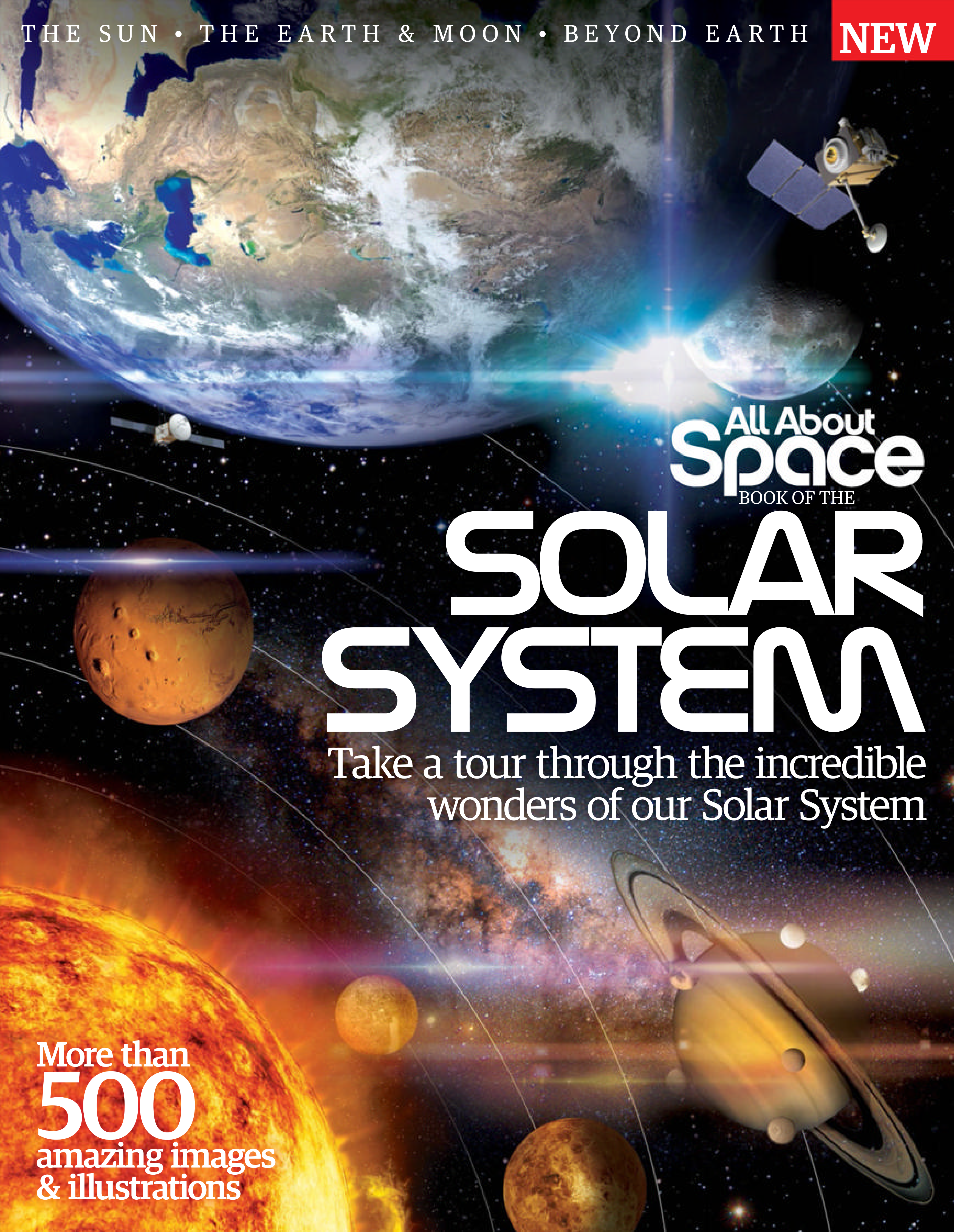

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SOLAR SYSTEM

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Over the centuries, humankind has dwelled on the question of how the Solar System came into being around 4.5 billion years ago. In the 21st Century, our pursuit of knowledge is as insatiable as ever, and new technology advances our understanding all the time. The more we know about the planetary system we live in, the closer we are to answering the conundrum of whether Earth – and humankind – are unique. Starting with the star at the heart of it all, the newly revised Book of the Solar System will take you on a guided tour of the essentials. How many rings does Saturn have? Is Mars capable of supporting life? Why is Venus described as our 'sister planet'? You will even get a closer look at our home planet and its only satellite. Discover what makes Earth's environment habitable, explore the Moon's surface and learn how the two entities interact. These questions and more are answered through essential guides accompanied by incredible imagery and illustrations, so you will soon feel at home with even our most hostile planetary neighbours!

All About Space
BOOK OF THE
SOLAR SYSTEM

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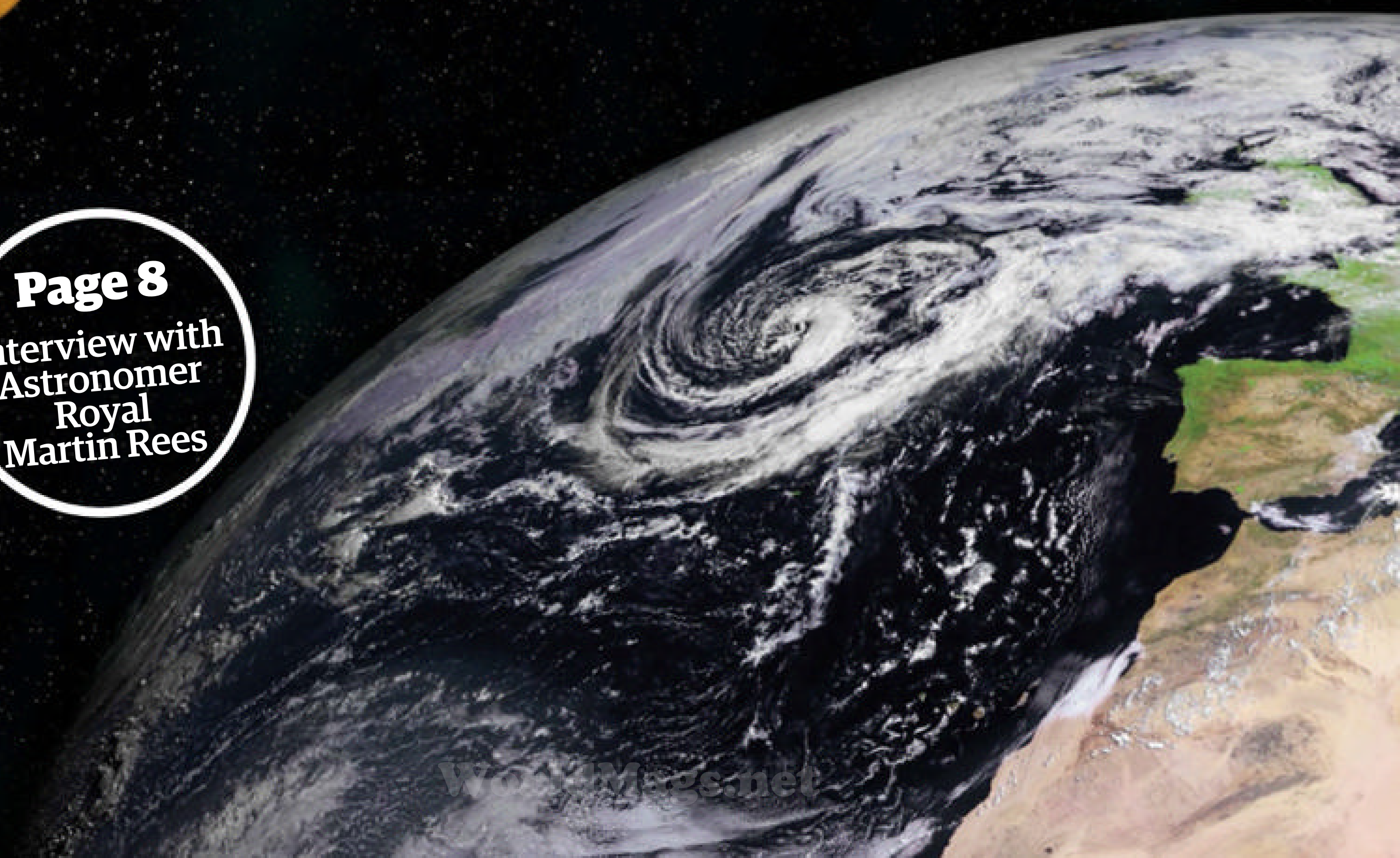


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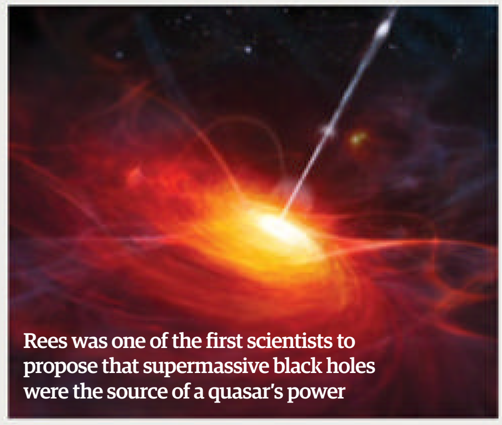
Astronomer Royal

The much-celebrated Astronomer Royal Martin Rees gives some quick answers on some of the most current events in popular astronomy

What, in your mind, is the greatest unanswered question of the solar system?
Whether there is life somewhere away from the Earth. There may be simple life on Mars, but the most interesting place to search would be the oceans under the ice of Europa and Enceladus.

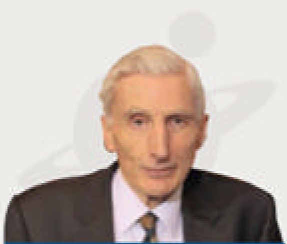
Do you think Pluto's demotion to a dwarf planet was an important distinction to make?
No, I don't think it mattered. If Pluto hadn't been discovered until recently, we'd have put it in the same class as several other objects in the outer Solar System (one of which is bigger than Pluto). We would therefore either call them all planets, or put them (with Pluto) in a separate category.


Rees was one of the first scientists to propose that supermassive black holes were the source of a quasar's power

Your support for the crowd-funded Lunar Mission One has been well publicised. What is there left to learn that was not achieved by the 1960-70s moon landings?
Many parts of the moon haven't been explored. We would like to learn more geology by digging below the surface. Especially interesting are the craters near the poles which are always in darkness and therefore could have persisting ice.

What is the probability that Earth will one day be hit by a comet or asteroid? What is the planet's chance of survival?
We know that the kind of asteroid that probably killed the dinosaurs hits the Earth once every few tens of million years. There's about one chance in a million that that's how we'll die (i.e. if it were to come soon). But smaller objects hit more frequently and could devastate a city or region. There are efforts to chart the orbits of the million asteroids more than 50 metres across, to identify any that might hit the Earth. Within 50 years it may be possible to deflect the orbit of such an object so it would miss us.

> "Most of us would want to take this historic first trip to Mars, even if it is one-way"



INTERVIEWBIO

Martin Rees
Renowned Astronomer Royal Martin Rees is best known for his work on some of the most exotic and extreme objects in the cosmos: black holes, quasars, gamma ray bursts and the early universe. He's written several books, has received numerous prestigious academic awards, he was the president of the Royal Astronomical Society and even has a seat in the UK's House of Lords, as Baron Rees of Ludlow.

Rees delivers his acceptance speech at the 2011 Templeton Prize award ceremony

HRH the Duke of Edinburgh bestows the Templeton Prize on Martin Rees

The Arecibo Observatory in Puerto Rico. Rees supports the work of SETI, but thinks it unlikely that life will be found elsewhere in the Solar System

The team behind the Planck spacecraft's Cosmic Microwave Background-exploring mission. The Big Bang theory has come far in the last 50 years

It has been reported that you believe sending humans into space is wasteful of time and money, but what do you make of projects like Virgin Galactic aimed at creating an industry of space tourism?
I hope people now living will walk on Mars. But they'll be embarking on a dangerous adventure. I think the phrase 'space tourism' is unfortunate as it lulls people into believing that space travel will be safe and 'routine'.

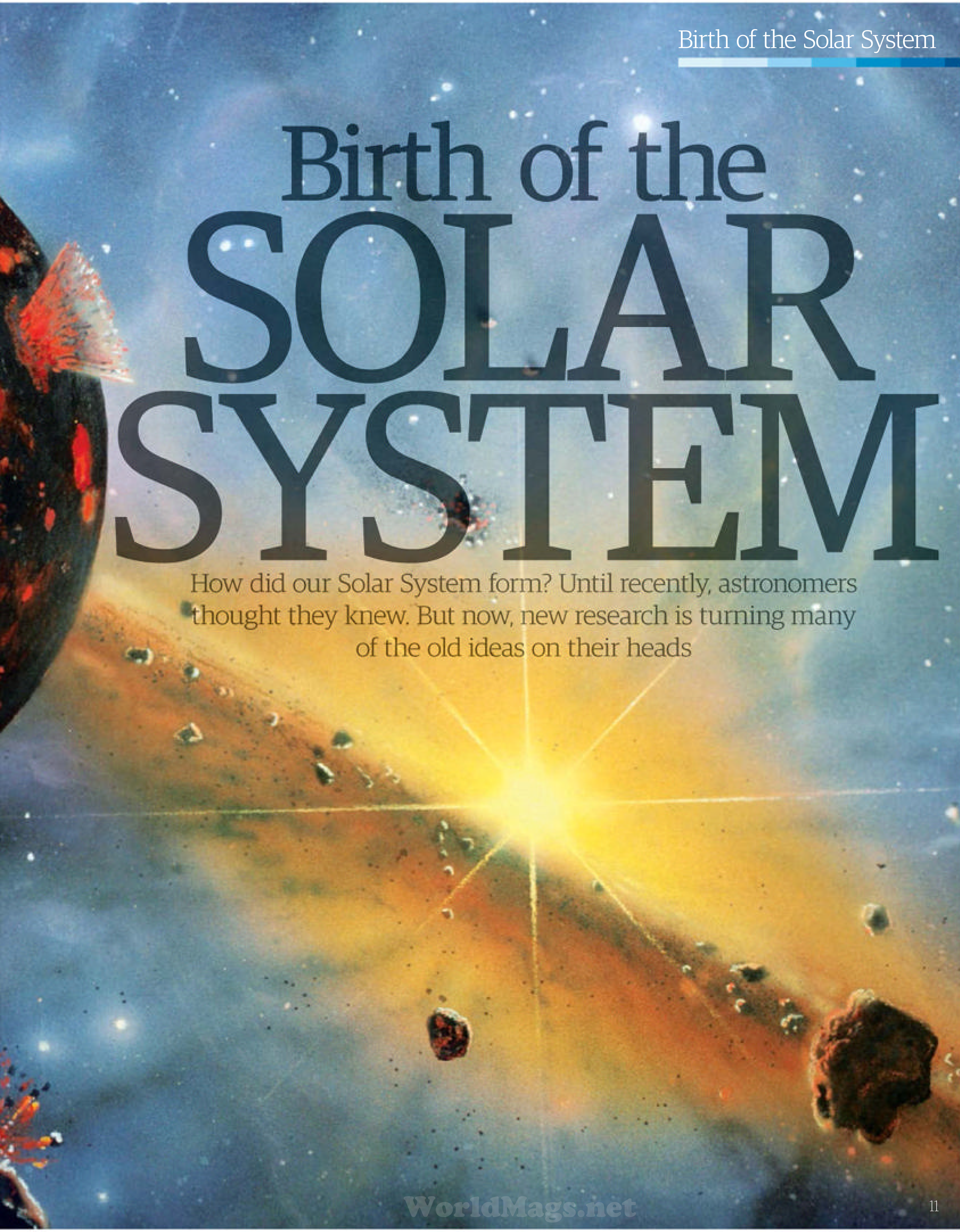
When do you think humans will land on Mars?
Probably within the next 50 years.

Do you understand the desire to be among the first Mars One crew to undertake the proposed one-way journey to settle on Mars in 2026?
Yes, I think most of us would wish to take this historic first-trip to Mars, even if they had a one-way ticket. But I'm very sceptical about anyone who claims to be able to do this by 2026.

Do you think there is enough interest among young people to learn about astronomy?
I'm surprised and gratified that there's so much interest - it's second only to dinosaurs in making young people aware of the mysteries of science!

What do you make of Google's Lunar XPrize?
A great idea which we can all cheer on.

Data from the ESA's Planck mission has been crucial in firming up theories by Martin Rees and other astronomers



Birth of the SOLAR SYSTEM

How did our Solar System form? Until recently, astronomers thought they knew. But now, new research is turning many of the old ideas on their heads

Around 4.5 billion years ago, our Sun and all the other objects that orbit around it were born from an enormous cloud of interstellar gas and dust, similar to the glowing emission nebulae we see scattered across today's night sky. Astronomers have understood this basic picture of the birth of the Solar System for a long time, but the details of just how the process happened have only become clear much more recently – and now new theories, discoveries and computer models are showing that the story is still far from complete. Today, it seems that not only did the planets form in a far more sudden and dynamic way than previously suspected, but also that the young Solar System was rather different from that we know now.

The so-called 'nebular hypothesis' – the idea that our Solar System arose from a collapsing cloud of gas and dust – has a long history. As early as 1734, Swedish philosopher Emanuel Swedenborg suggested that the planets were born from clouds of material ejected by the Sun, while in 1755 the German thinker Immanuel Kant suggested that both the Sun and planets formed alongside each other from a more extensive cloud collapsing under its own gravity. In 1796, French mathematician Pierre-Simon Laplace produced a more detailed version of Kant's theory, explaining how the Solar System formed from an initially shapeless cloud. Collisions within the cloud caused it to flatten out into a spinning disc, while the concentration of mass towards the centre caused it to spin faster (just as a pirouetting ice skater spins faster when they pull their arms inwards).

In the broad strokes described above, Laplace's model is now known to be more or less correct, but he certainly got some details wrong, and left some crucial questions unanswered – just how and why did the planets arise from the nebula? And why didn't the Sun, concentrating more than 99 per cent of the Solar System's mass at the very centre of the system, spin much faster than it does? Solutions to these problems would not come until the late 20th Century, and some of them are still causing doubts even today.

Much of what we know about the birth of our Solar System comes from observing other star systems going through the same process today. Stars are born in and around huge glowing clouds of gas and dust, tens of light years across, called emission nebulae (well known examples include the Orion Nebula, and the Lagoon Nebula in Sagittarius). The nebulae glow in a similar way to a neon lamp, energised by radiation from the hottest, brightest and most massive stars within them, and remain active for perhaps a few million years, during which time they may give rise to hundreds of stars forming a loose star cluster. Since the brilliant, massive stars age and die rapidly, it's only the more sedate, lower-mass stars like our own Sun that outlive both the nebula and the slow disintegration of the star cluster.

Star birth nebulae develop from the vast amounts of normally unseen, dark gas and dust that forms the skeleton of our Milky Way galaxy, and subside as the fierce radiation from their most massive stars literally blows them apart. The initial collapse that kick-starts formation can be triggered in several ways – for instance by a shockwave from a nearby exploding supernova, or by tides raised during close encounters with other stars. However, the biggest waves of star birth are triggered when material orbiting in our galaxy's flattened outer disc drift through a spiral-shaped region of compression that extends from the galactic hub and gives rise to our galaxy's characteristic shape.

Inside the nebula, stars are incubated in huge opaque pillars of gas and dust. As these pillars are eroded by outside radiation from massive stars that have already formed, they break apart into isolated dark globules whose internal gravity is strong enough to hold them together – the seeds of individual solar systems. Gas falling towards the very centre of the globule becomes concentrated, growing hotter and denser until eventually conditions are right for nuclear fusion, the process that powers the stars, to begin. As the star begins to generate energy of its own, its collapse stabilises, leaving an unpredictable stellar newborn surrounded by a vast disc of gas and dust that will go on to form its solar system. But how? That's where things get really interesting…

The first person to put Laplace's hypothesis on a sound theoretical footing was Soviet astronomer Viktor Safronov, whose work was first translated from Russian around 1972. Safronov's modified 'solar nebular disk model' allowed the Solar System to form from much less material, helping to resolve the problem of the Sun's slow spin. What was more, Safronov provided a basic mechanism for building planets out of primordial dust grains, known as 'collisional accretion'.

This simple mechanism involves small particles colliding and sticking to each other one at a time, eventually growing into objects that were large enough to exert gravitational pull and drag in more material from their surroundings. This produced

"Much of what we know about the birth of our Solar System comes from observing other star systems"

How stars are formed

Disturbed nebula
The birth of a star begins when a cloud of interstellar gas and dust passes through a galactic density wave, or is compressed by shock from a nearby supernova or tides from a passing star

Slow collapse
Denser regions within the nebula start to collapse under their own gravity. As mass concentrates towards their centres, they begin to spin more rapidly, and their cores grow hotter

Flattening disc
Collisions between randomly moving gas clouds and dust particles tend to flatten out their motions into a narrow plane, creating a disc that spins ever more rapidly

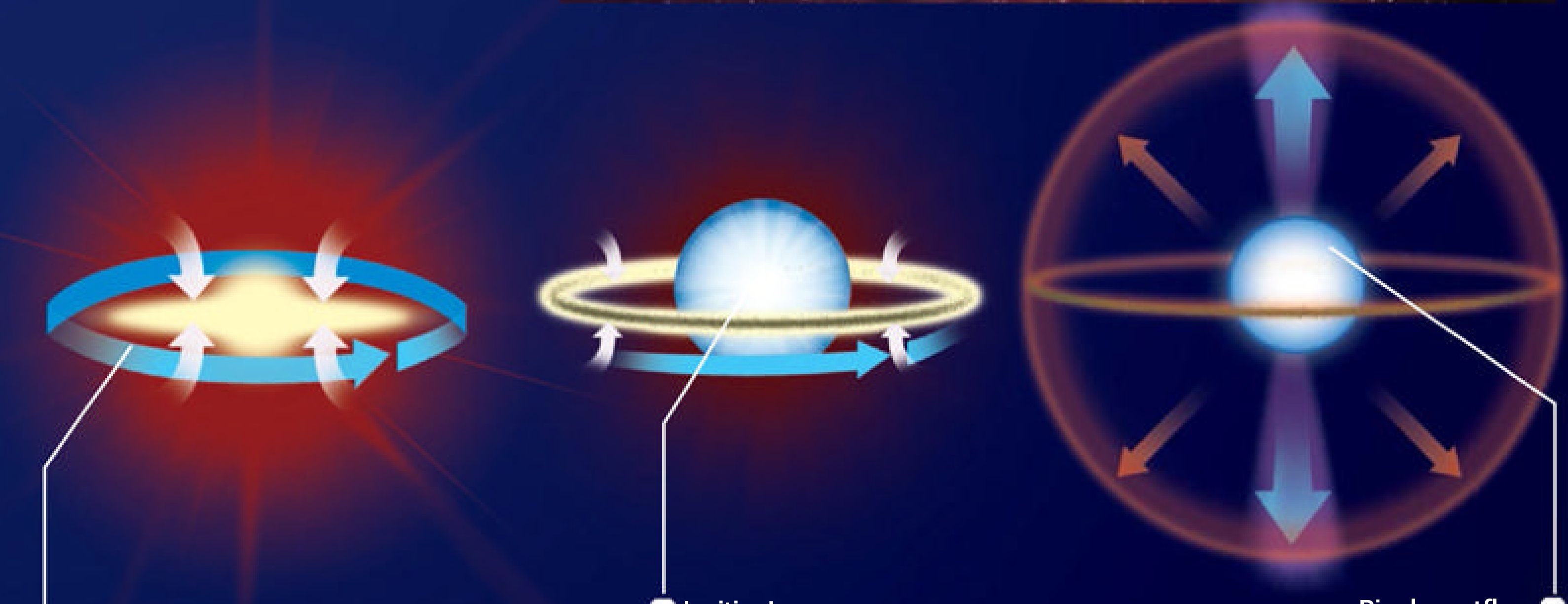
objects called planetesimals, the largest of which might have been about the size of the dwarf planet Pluto. A final series of collisions between these small worlds created the rocky planets close to the Sun, and the cores of the giant planets further from the Sun. The difference between the two main types of planet is then explained by the existence of a 'snow line' in the early Solar System, around the location of the present-day asteroid belt. Sunward of this, it was too warm for frozen water or other chemical ices to persist - only rocky material with high melting points survived. Beyond the snow line, however, huge amounts of ice and gas persisted for long enough to be swept up by the giant planets.

It all sounds simple enough, and has been widely accepted for the best part of four decades. But now that seems to be changing. "There's been the beginning of a paradigm shift away from the two-body build-up that Safronov modelled," says Dr Hal Levison of the Southwest Research Institute (SwRI) in Boulder, Colorado. "The idea of things growing by collisions hasn't really changed but over the last five years or so, new theories invoking the idea of pebbles [are] coming to the fore. We've really only now got to the stage where we can discuss these ideas in any great detail."

The new approach stems from a long-standing problem: "The big question is how you get the first macroscopic objects in the Solar System - things that are bigger than, say, your fist," explains Levison. "Safronov's idea was that you just did that through collisions, but people have always recognised there's a problem we call the metre barrier."

"You only have to look under your bed to see plenty of evidence that when small things hit one another, they can stick together, making these dust bunny clumps that are held together by electrostatic forces [weak attraction between innate static electric charges]. And if you look at objects bigger than, say

Known as N90, this emission nebula in the Small Magellanic Cloud shows many features associated with the birth of stars, with a central cluster dominated by heavyweight stars, and stalactite-like opaque pillars where star birth is still continuing



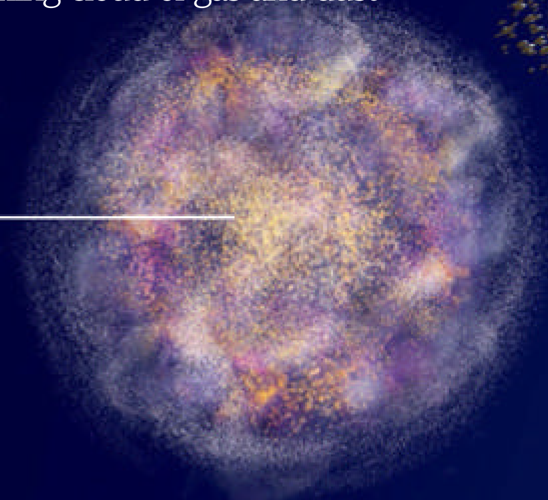
Birth of a protostar
As more and more material falls into the core of the nebula, it starts to radiate substantial infrared radiation that pushes back against the tendency to collapse. The core of the nebula is now a protostar

Ignition!
Finally, conditions at the heart of the protostar become hot and dense enough for nuclear fusion to begin converting hydrogen into helium. The star now begins to shine properly, but goes through violent fluctuations before it stabilises

Bipolar outflow
Gas continues to fall onto the infant star, accumulating around its equator but being flung off at its poles in jets known as bipolar outflow. Radiation pressure starts to drive gas out of the surviving nebula

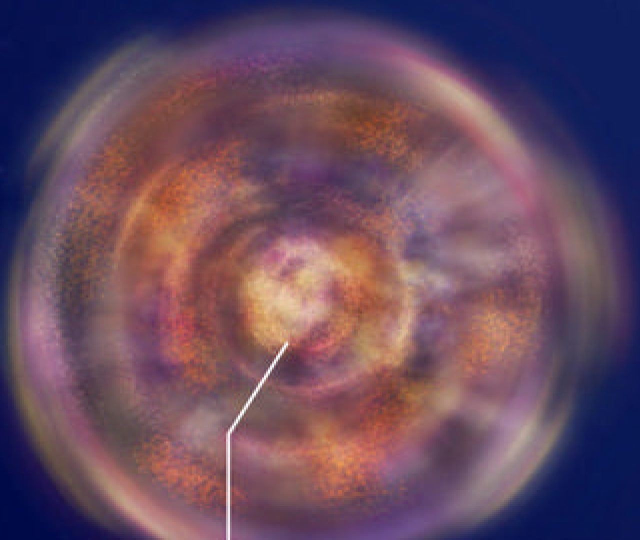
The birth of the planets

Our Solar System was cooked up in a swirling cloud of gas and dust



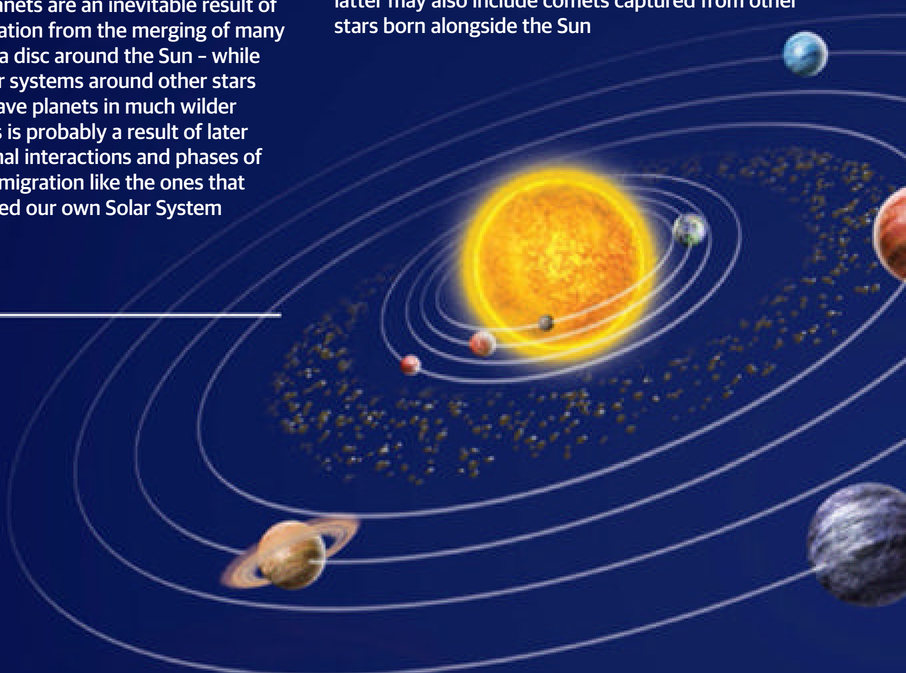
1 Shapeless cloud
About 4.5 billion years ago, the raw materials of the Solar System lay in a shapeless cloud of gas and dust. Its dominant components were hydrogen and helium, but it was also enriched with elements created by previous generations of stars, and scattered through the so-called interstellar medium. These included carbon, oxygen and nitrogen, as well as dust grains (often carbon-based) up to one micrometre (0.001mm or 4x10^{-5}in) across

2 Collapse begins
The trigger event for the formation of an emission nebula typically produces condensation in several regions of the cloud that happen to have higher densities. Each may give rise to a whole group of stars – once the first stellar heavyweights have begun to shine, their radiation helps energise the nebula, and also sculpts its shape, dictating where the younger generations of stars will form. However, by blowing material out of the nebula, these early giants also stunt the growth of their siblings



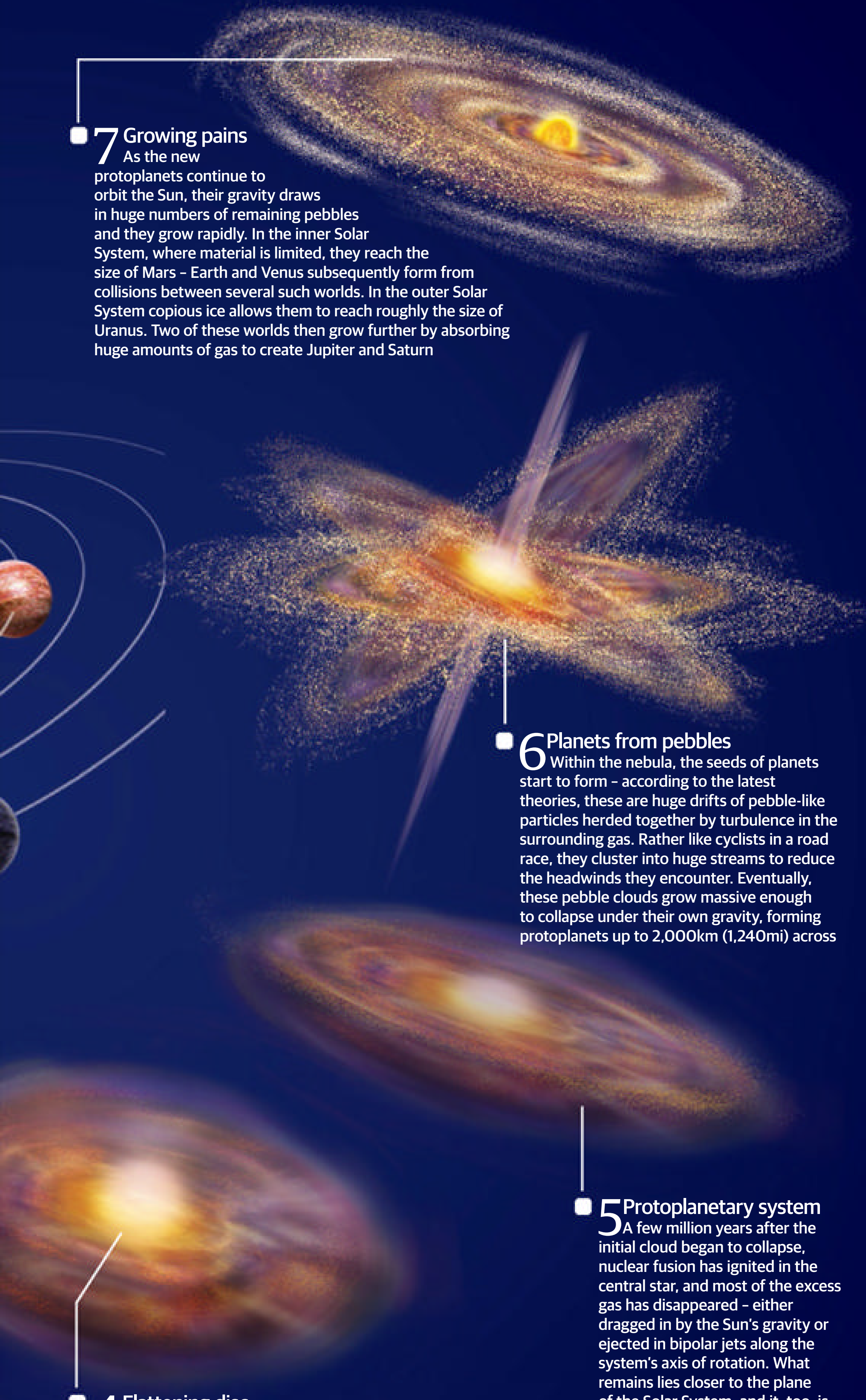
3 Individual systems
A single globule of collapsing gas and dust may give rise to a single star of a multiple star system at its centre. As material falls inward, collisions between gas clouds and particles tend to cancel out movements in opposing directions, while an effect known as the conservation of angular momentum causes the cloud's central regions to spin faster as most of the mass concentrates there

8 Planetary migrations
During one or more phases of planetary migration, the giant planets of the outer Solar System change their configurations and locations, moving back and forth through a host of smaller bodies (asteroids, small comets formed between the giant planets, or ice dwarfs orbiting beyond). The havoc they wreak ultimately gives rise to the modern asteroid belt, Kuiper belt and Oort cloud, though the latter may also include comets captured from other stars born alongside the Sun



9 The Solar System today
The neat, near-circular orbits of today's planets are an inevitable result of their formation from the merging of many objects in a disc around the Sun – while many solar systems around other stars seem to have planets in much wilder orbits, this is probably a result of later gravitational interactions and phases of planetary migration like the ones that once shaped our own Solar System

> "The old idea of getting to Mars-sized objects by banging Moon-sized things together could be wrong"



7 Growing pains
As the new protoplanets continue to orbit the Sun, their gravity draws in huge numbers of remaining pebbles and they grow rapidly. In the inner Solar System, where material is limited, they reach the size of Mars – Earth and Venus subsequently form from collisions between several such worlds. In the outer Solar System copious ice allows them to reach roughly the size of Uranus. Two of these worlds then grow further by absorbing huge amounts of gas to create Jupiter and Saturn

6 Planets from pebbles
Within the nebula, the seeds of planets start to form – according to the latest theories, these are huge drifts of pebble-like particles herded together by turbulence in the surrounding gas. Rather like cyclists in a road race, they cluster into huge streams to reduce the headwinds they encounter. Eventually, these pebble clouds grow massive enough to collapse under their own gravity, forming protoplanets up to 2,000km (1,240mi) across

5 Protoplanetary system
A few million years after the initial cloud began to collapse, nuclear fusion has ignited in the central star, and most of the excess gas has disappeared – either dragged in by the Sun's gravity or ejected in bipolar jets along the system's axis of rotation. What remains lies closer to the plane of the Solar System, and it, too, is gradually being driven away by the Sun's radiation

4 Flattening disc
The end result of the cloud's collapse is a spinning disc with an orientation derived from the slow random rotation of the original globule. Dust and ice particles tend to concentrate more efficiently around the central plane of this disc, while gas forms a looser halo, and continues to fall in towards the central regions until conditions there become extreme enough to create one or more protostars

a few kilometres across, gravity can hold things together. But if you're looking at something, say, the size of a boulder, then it's hard to imagine what makes those things stick."

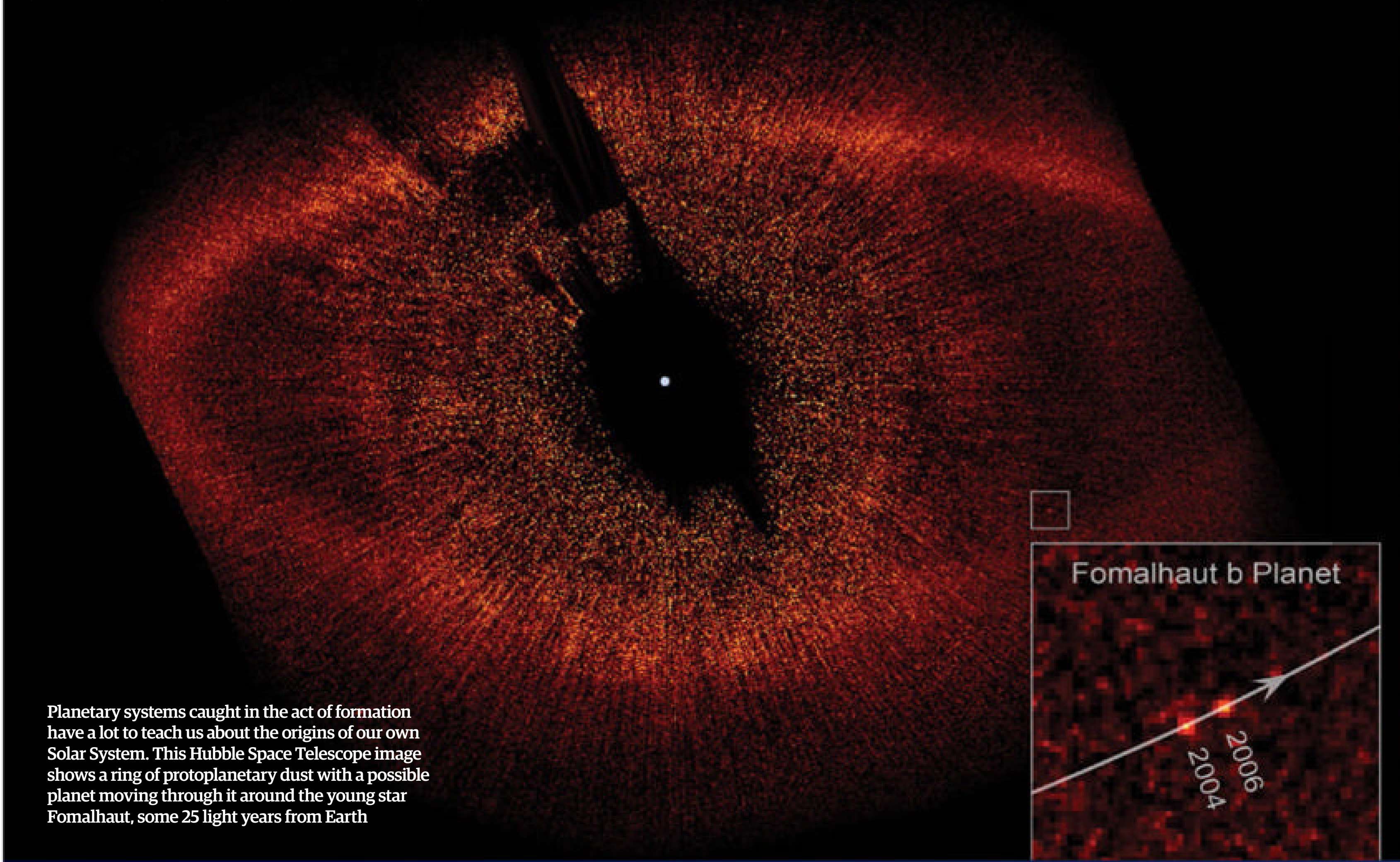
Fortunately about ten years ago, researchers including Andrew Youdin (University of Arizona) and Anders Johansen (now at Sweden's Lund University) came up with an ingenious way around the problem. "What they've shown is that as dust grains settle into the central plane of the protoplanetary disc, that causes a kind of turbulence that concentrates the pebbles into large clumps," continues Levison. "And eventually these clumps can become gravitationally unstable and collapse to form really big objects. This model predicts that you go directly from things the size of your fingernail to hundred-kilometre [62-mile]-sized objects, in just one orbit around the Sun."

Over the past few years, as various teams including Levison's group at SwRI have worked on the theory, they've found that the clumping process is even more effective than they first thought: "We're talking about objects up to the size of Pluto forming this way, out of pebbles." And that's just the first stage: "Once you get up to that size, you get a body that can grow very effectively by eating the surrounding pebbles, pulling stuff in with its gravity and maybe growing into something the size of Mars. So the old idea of getting to Mars-sized objects by banging a lot of Moon-sized things together could be wrong."

This new theory could help solve several outstanding problems with the Solar System, such as the relative ages of the Earth and Mars. "Mars seems to have formed about 2 to 4 million years after the Sun formed, while Earth formed about 100 million years later," explains Levison. The theory, then, is that Mars was entirely formed by the two stages of the pebble accretion process, while Earth still had to go through a final phase of Safronov-style planet-scale collisions in order to reach its present size.

"Pebbles can also help to explain how the giant planets formed as quickly as they did," Levison enthuses. "Most astronomers accept the 'core accretion' model for the giant planets, where you start out with four objects the size of Uranus and Neptune, and two of those then accumulate gas and grow to become Jupiter and Saturn. But the problem is that you need to build those cores before all the gas goes away. In the traditional Safronov model, that's hard to do, but again this new pebble accretion model can do it really quickly." The difference in scale between the Mars-sized rocky objects and the much larger giant-planet cores, meanwhile, is still to do with availability of raw material, with copious icy pebbles surviving only in the outer Solar System.

But there's one other big problem in matching the Solar System we know today with the original solar nebula – the positions of the planets, and in particular the cold worlds of the outer Solar System. Today, Uranus orbits at a distance of 2.9 billion kilometres (1.8 billion miles) from the Sun, and Neptune at 4.5 billion kilometres (2.8 billion miles). Beyond Neptune, the Kuiper belt of small, icy worlds (including Pluto and Eris) extends to



Planetary systems caught in the act of formation have a lot to teach us about the origins of our own Solar System. This Hubble Space Telescope image shows a ring of protoplanetary dust with a possible planet moving through it around the young star Fomalhaut, some 25 light years from Earth

"The new pebble accretion model can help to explain how the giant planets formed as quickly as they did" **Dr Hal Levison**

more than twice that distance, and then there's the Oort cloud – a vast spherical halo of icy comets that extends to around 15 trillion kilometres (9.3 trillion miles). The solar nebula, meanwhile, would have been most concentrated around the present orbit of Jupiter, and trailed off from there – while computer models suggest Uranus and Neptune could not have grown to their present size unless they were closer to Jupiter and Saturn.

All of which brings us to the work for which Levison is perhaps best known – his contribution to the so-called 'Nice model' of planetary migration. This explains the current configuration of the Solar System as the result of the dramatic shifting of the planets that happened around 500 million years after its formation.

"The Nice model goes back some ten years now," recalls Levison. "It postulated a very compact configuration for the outer planets when they formed, with Jupiter and Saturn, probably Neptune next, and then Uranus all orbiting in the outer Solar System, and beyond that, a disc of material with the mass of about 20 Earths. The biggest objects inside that disc would have been about the size of Pluto."

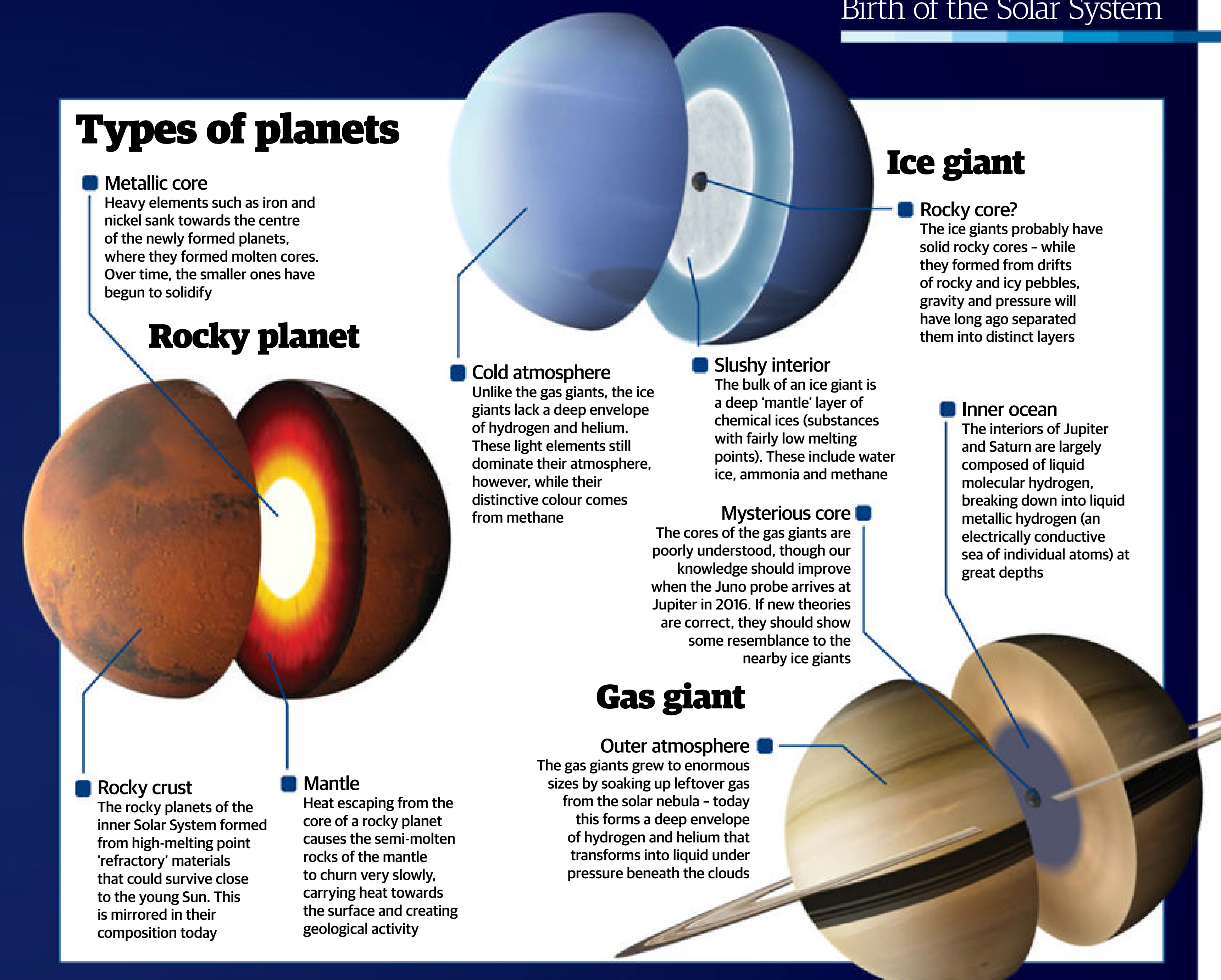
In the Nice scenario, all four giant planets formed within the present-day orbit of Uranus, with the Kuiper belt extending to about twice that diameter, yet still inside the current orbit of Neptune. But this arrangement was doomed to instability, and around 4 billion years ago, Uranus and Neptune began a series of close encounters that disrupted their orbits and put them onto new paths around the Sun.

Now, for various reasons, the orbits of Uranus and Neptune became unstable – they started having encounters with each other that threw them into orbits going all over the Solar System, and then having encounters with Jupiter and Saturn.

"Before too long, they began having encounters with Jupiter and Saturn," continues Levison, "and the gravity of these giant planets threw them out into the disc of Kuiper belt objects. Gravitational interactions between Uranus, Neptune and these objects circularised the orbits of the giant planets, and ejected most of the smaller objects either out into the present-day Kuiper belt, or in towards the Sun. It was a very violent, short-lived event lasting just a few tens of million of years, and we think we see the evidence for it on the Moon, where the impact rate went up around 4 billion years ago in an event called the Late Heavy Bombardment."

Perhaps unsurprisingly, the Nice model has been tweaked a little in the decade since its first publication: "The exact mechanism that causes the instability has changed a bit, and there's work by

Comets are icy remnants left over from the early days of the Solar System, and may have a lot to tell us about its raw materials and early dynamics. However, Hal Levison has argued that the distant Oort cloud could also have been enriched by comets swept up from the Sun's siblings in its birth cluster



David Nesvorny, here at SwRI, arguing that you're more likely to end up producing the Solar System that we see if there were initially three ice giants instead of two, and we lost one during the process."

Mention of the Moon's late bombardment raises an interesting question – could some form of planetary migration also help resolve the long-standing question of where Earth's water came from? According to current theories, the environment in which the planets formed was a dry one, so the theory that our present-day water arrived later, from somewhere else in the Solar System, is a popular one. Yet measurements from comet probes such as ESA's Rosetta shows subtle but important differences from the water found on Earth.

"In fact, Jupiter wields too big of a baseball bat for comets to have made much of a contribution to water on Earth," points out Hal Levison. "Its gravity simply forms too big a barrier between the outer and inner Solar Systems, so, at most, ten per cent of water on Earth could have come from comets. We've known that for some time from dynamics

"Jupiter wields too big of a baseball bat for comets to have made much of a contribution to water on Earth" **Dr Hal Levison**

– we don't really need the cosmochemical measurements taken by probes like Rosetta to prove that. Instead, Earth's water probably came from objects in the outer asteroid belt, and there's a separate planetary migration model called the Grand Tack that offers one way to do that, though I think it has some problems."

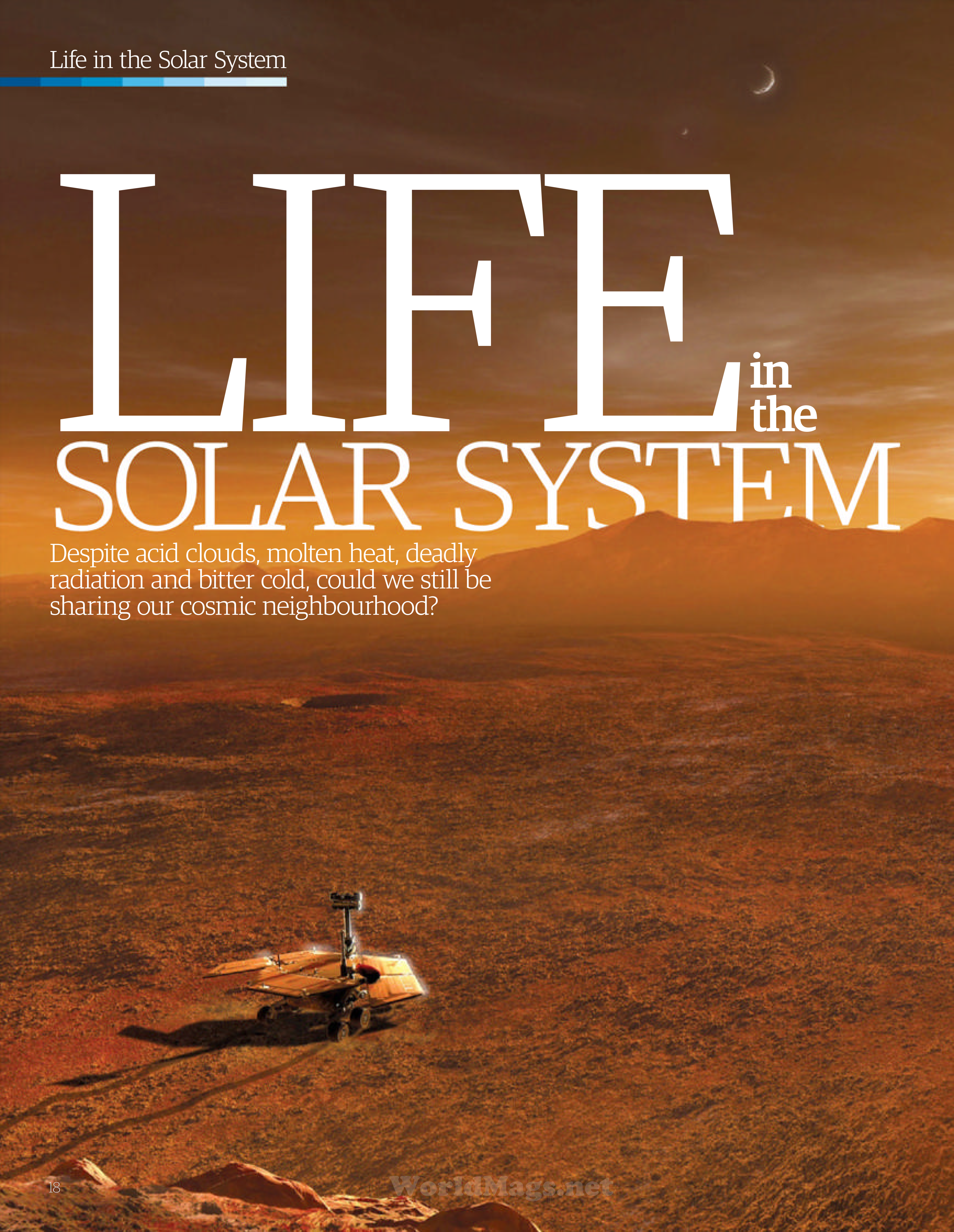
The Grand Tack is part of the planet formation story itself – it involves Jupiter moving first towards, and then away from the Sun, due to interaction with gas in the solar nebula. In the process, its gravitational influence robbed Mars of the material required to grow into an Earth-sized planet, but later enriched the outer asteroid belt with water-rich bodies that might later have found their way to Earth. If that's the case, then Japan's recently launched Hayabusa 2 probe, which aims to survey a nearby asteroid and return samples to Earth around 2020, could provide more information if it discovers Earth-like water in its target, a small body called 1999 JU3.

"The Grand Tack is one way of solving the problem of why Mars has just ten per cent of the mass of Earth and Venus, when most models predict it should be just as massive if not more so, but the pebble accretion work we're doing may also solve it," argues Levison.

It seems clear, then, that it's an exciting time for scientists probing the origins of the Solar System – who would have thought, a few short years ago, that so many answers might lie in the realm of seemingly insignificant interplanetary pebbles?

LIFE in the SOLAR SYSTEM

Despite acid clouds, molten heat, deadly radiation and bitter cold, could we still be sharing our cosmic neighbourhood?



On the north-eastern border of the vast Vatnajökull glacier, Iceland, lies the Kverkfjöll mountain range, where a string of active volcanoes pepper the bleak, Icelandic landscape. Deep under the mountains, searing-hot magma gathers in cavernous chambers. Heat escaping from the chambers warms the glacial ice overhead, sculpting it into a spectacular ice cave some 2.8 kilometres (1.7 miles) long. The melted water crafts lakes that would freeze were it not for the hydrothermal energy escaping from the seething molten rock below.

These hot, acidic lakes may not seem like the most hospitable of places, but bacteria have made a home here. Ian Crawford, professor of planetary science and astrobiology at Birbeck, University of London, studies these hardy organisms. "Part of my work is sampling the water from these boiling, acidic lakes," he says. "We want to get an insight into the adaptations that life has had to make in order to exist there." These bacteria are just one example of extremophiles – life forms that don't just survive, but actively thrive in conditions once thought incredibly hostile. Halophiles have an incredibly high tolerance to salt, xerophiles persist in some of the driest places on the planet, while alkaliphiles flourish in highly alkaline locations.

The fact that life has been found eking out an existence in remote, desolate places on Earth has raised hopes of finding life doing the same in some of the more extreme environments elsewhere in our Solar System. Ian Crawford's investigations in Iceland are helping us hunt for potentially habitable environments on Mars, for example. "Being boiled by acidic water alters the surrounding rock in a way that you can spot," he says. It's thought that the interaction between volcanoes and ice would have been a very common feature in Mars's history too. Recent Mars rovers have been equipped with instruments to detect the alterations to rock that Crawford describes, enabling them to hunt down areas on the Martian surface that could possibly have once been home to hydrothermal pools. "Mars probably isn't habitable now, but it may have been in the past," Crawford explains. Even finding evidence of long-extinct life on the Red Planet would be a remarkable achievement.

Mars is perhaps the planet that has captured the human imagination more than any other. Thanks to an army of rovers, landers and orbiters, we certainly know more about the planet than its other neighbours that we share the Solar System with. In fact, we know more about some parts of Mars than we do about parts of our own planet – we even have a better map of the Martian surface than we do of the ocean floor here on Earth. During more than ten years of orbiting Mars, the European Space Agency (ESA) Mars Express mission has imaged more than 95 per cent of the surface.

A total of four Mars rovers – robots that are driven by remote control from Earth – have been successfully deployed. Rovers Sojourner and Spirit have since been retired, while Opportunity and Curiosity are still active, with the latter recently celebrating its second anniversary of Mars exploration. Together they have revolutionised our understanding of the planet. As well as sending back glorious images, including spectacular Martian

sunsets, they have scoured the surface looking for evidence that Mars was once habitable. What they have found so far is enticing.

It seems that Mars used to be a warmer, wetter planet, with a much thicker atmosphere. Also, as much as a third of its surface was once covered with water. When Curiosity touched down in Gale Crater (which surrounds Mount Sharp on the Martian equator) and surveyed its new surroundings, its measurements suggested the landing site was once an expansive freshwater lake. When the rover drilled through local mudstones, it found minerals and nutrients that, coupled with the water, would have made the crater a distinctly habitable environment.

So the idea that Mars was once home to life billions of years ago is far from ridiculous. It is far more unlikely, however, that life persists on Mars today. The once wet planet is now an arid, dusty desert with only a thin atmosphere to protect any life from the many dangers of outer space. It seems the planet entered a climatic decline around 3.8 billion years ago. "Any life on the very surface would have died within a few million years, sterilised by cosmic radiation from the Sun and supernovae throughout the galaxy," says Dr. Lewis Dartnell, an astrobiologist at the University of Leicester. Dartnell's work has included taking extremophiles from the Dry Valleys of Antarctica - one of the most Mars-like places on Earth - and blasting them with radiation to see how they fare. Not well, it turns out.

Contrary to popular belief, not one of the four successful Mars rovers has been equipped with instruments capable of detecting life - it's not what they were designed for. They've looked instead for evidence that the Red Planet had - or has - environments capable of supporting life. In other words, the right mix of water and nutrients, but not life itself. However, there have been two missions to Mars carrying the necessary tools to look directly for life: Viking 1 and 2 landers. The two NASA probes touched down on the Martian surface in 1976 and while they didn't move across the surface like the rovers, they were equipped with robotic arms capable of reaching out and scooping up samples of the Martian soil. These samples were then analysed for any signatures of life, but no such evidence was found by either probe.

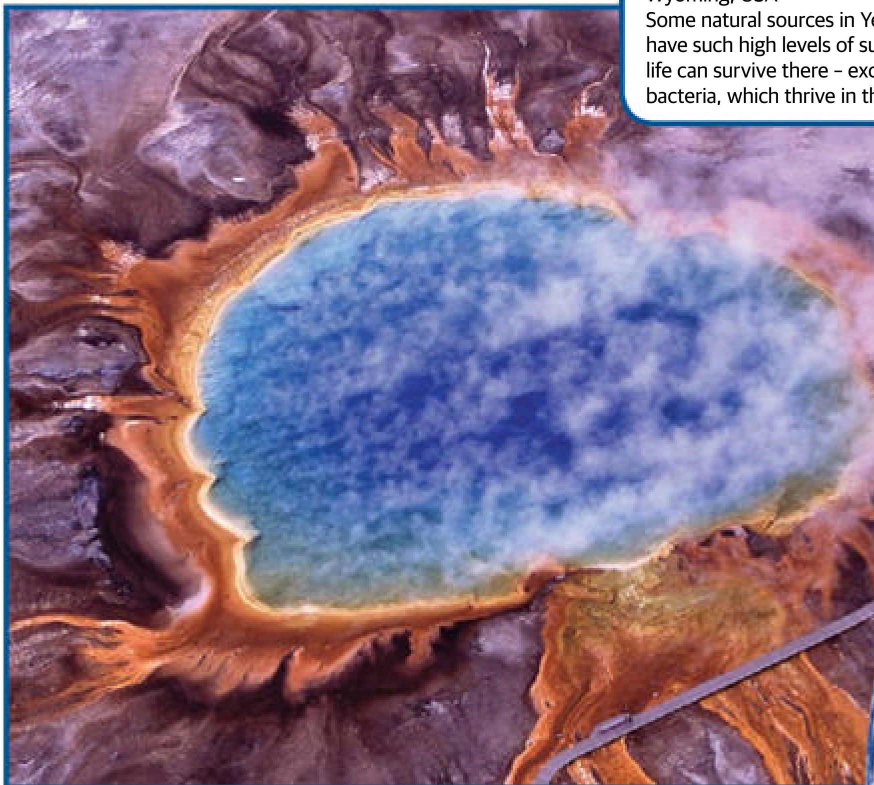
This may be about to change, however. The first rover equipped with the right hardware to directly search for Martian life could be launched as early as 2018. ESA's ExoMars mission will have something that no previous rover has had: a sizeable drill. "ExoMars's drill will be two metres (6.6 feet) long - Curiosity's is only the length of your little finger," says Dartnell, who is working on the mission. Digging down under the Martian surface will enable scientists to probe a region where ancient life may have remained shielded from space radiation. ExoMars will also be armed with a panoramic camera - PanCam - that has been designed to look for similar changes in rocks to those seen by Ian Crawford in Iceland. It will be capable of looking for evidence that living organisms - past or present - have altered the texture of Martian rocks.

The answer to whether life ever got started on Mars, or perhaps is still there, may one day come from intricate and innovative missions. However, Mars isn't the only place in the Solar System that might be home to extraterrestrial life forms. It's possible that living organisms have made a home high in the clouds of our nearest planetary neighbour: Venus.

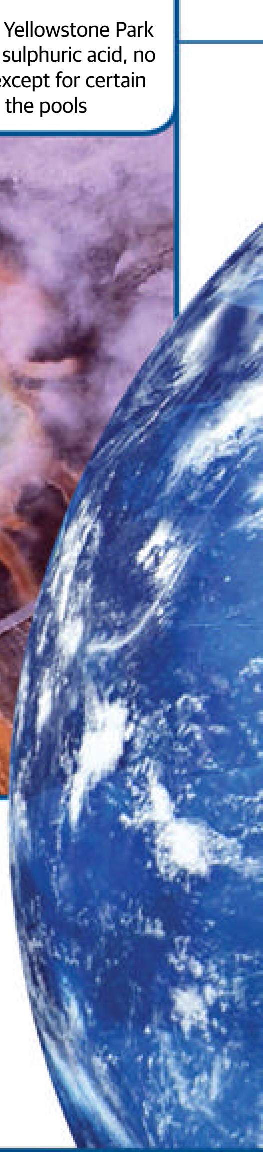
Venus, which is 95 per cent of the size of Earth and almost 1.5 times closer than us to the Sun, is hardly the poster child for habitability. Despite not being the closest planet to the Sun, it is the Solar System's hottest planet, engulfed by a stifling carbon dioxide atmosphere and thick clouds of sulphuric acid that trap the Sun's heat like a giant greenhouse. This leads to an average temperature of around 465 degrees Celsius (869 Fahrenheit), nearly three times hotter than Mercury's average. Despite its aggressive planetary persona, life on the second planet from the

"The answer to whether life ever got started on Mars, or perhaps is still there, may one day come from intricate and innovative missions"

Earth's extreme environments

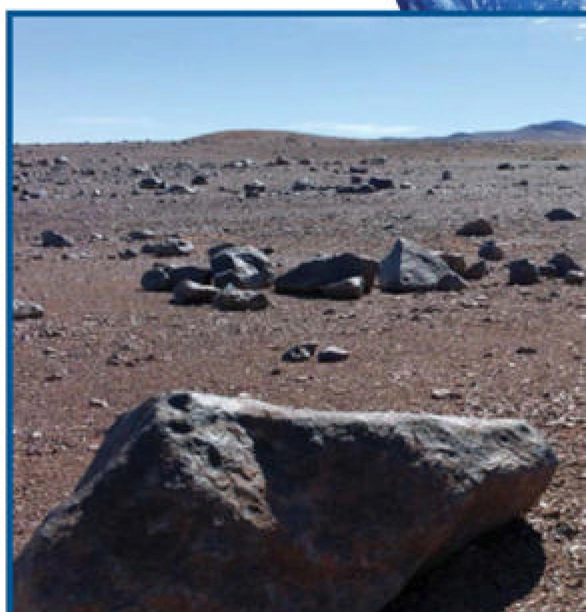


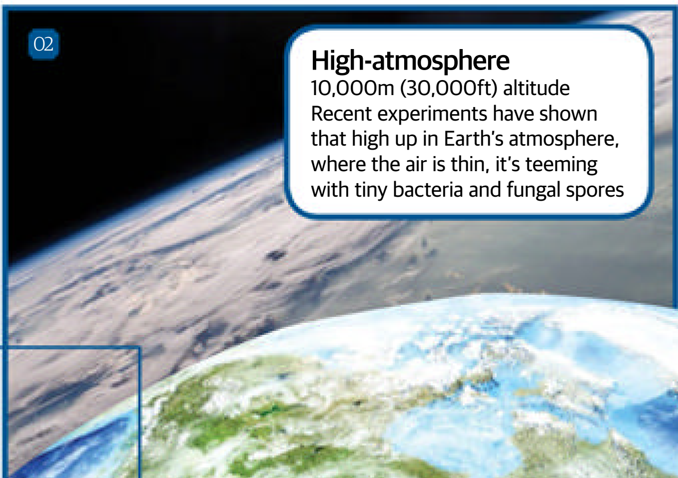
Yellowstone Hot Springs
Wyoming, USA
Some natural sources in Yellowstone Park have such high levels of sulphuric acid, no life can survive there – except for certain bacteria, which thrive in the pools



Key

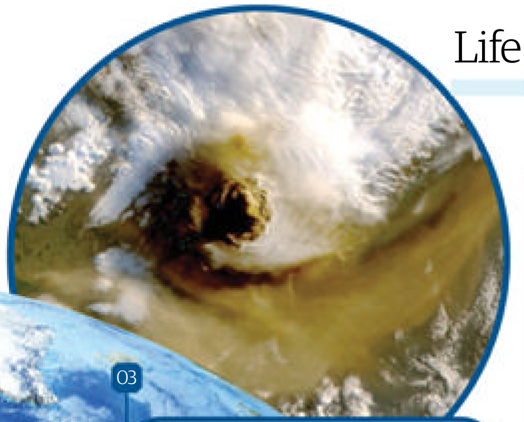
01 Acidic
02 Thin air
03 Molten heat
04 Extreme dryness
05 Freezing cold





02

High-atmosphere
10,000m (30,000ft) altitude
Recent experiments have shown that high up in Earth's atmosphere, where the air is thin, it's teeming with tiny bacteria and fungal spores



03

Grímsvötn Volcano
Iceland
Some life thrives around the activity of a volcano, and bacteria have been found to breed quite happily in the boiling lakes kicked up by Iceland's grinding tectonics

01

04

Atacama desert
Chile
Not much lives, grows or survives in the driest place on Earth outside of this desert's many telescope buildings, but just below the surface is a haven for bacteria

05

Lake Vostok
Antarctica
In a subglacial lake situated in the coldest place on Earth, living bacteria have been found, locked beneath the ice for a countless number of millennia

Planetary habitats

Mars
02 04
The Red Planet is very dry, has a thin atmosphere and once had running water on its surface. At the very least, it could have been a viable habitat for extremophile life

Venus
01 03
We probably don't need to look as far as the crushing pressure and heat of Venus' surface: its clouds could be a perfect environment for acid-loving organisms

Pluto
05
The dwarf planet is probably one of the most unlikely candidates for life in the Solar System and yet, scientists won't rule out the potential of its icy oceans

Sun is not being ruled out. "Conditions high up in the cloud decks aren't dissimilar to Earth. They are very acidic, but we know from studies of extremophiles on Earth that life can survive such harsh conditions," Dartnell explains.

Bacteria have already been found living high in the atmosphere on Earth, at similar heights to where human beings are only found strapped into a pressurised aeroplane cabin. Despite the much thinner air, significantly lower temperatures and increased exposure to ultraviolet radiation, bacteria are abundant there, so it's not beyond the realms of possibility that the same is true of Venus. However, unlike Earth, any Venusian life would always need to maintain its altitude - drop too low and it would be crushed, baked and dissolved.

The key question, then, is where such life would have originated. Earth's lofty bacteria are likely to have started much closer to the surface before being carried to altitude. Conditions on the Venusian surface today are too harsh to cradle life, but that might not have always been the case. "Venus may have started out similar to Earth," says Dartnell. A runaway greenhouse effect - perhaps starting just a few billion years ago - then turned it into the hellish cauldron it is today. If life got started on Venus when conditions were more favourable, some of that life may still be clinging on in the only place it can: high up in the clouds.

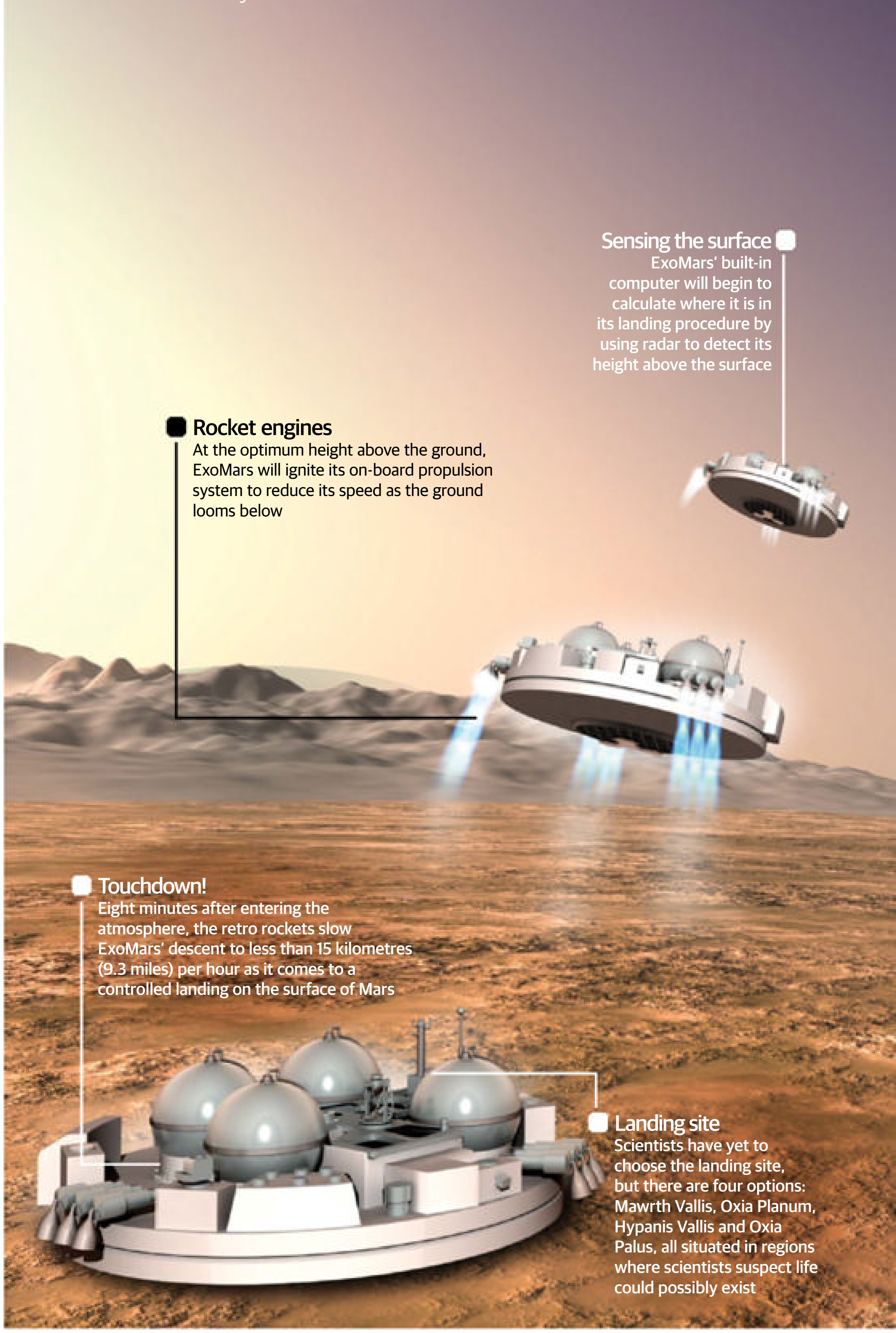
While bacterial life may be hidden away on the planets either side of us, our own planet is the one positively teeming with life. The extremophiles are an illustration of the broad range of environments life has colonised here. Almost all that life, from the tiniest bacteria to the biggest blue whale, has one thing in common: the need for liquid water. In this respect, Earth is in an ideal location. It isn't too close to the Sun, like Venus, where the temperatures soar and water evaporates. Nor do we orbit as far as Mars, where water is abundant but only persists for any length of time locked up in sprawling sheets of ice.

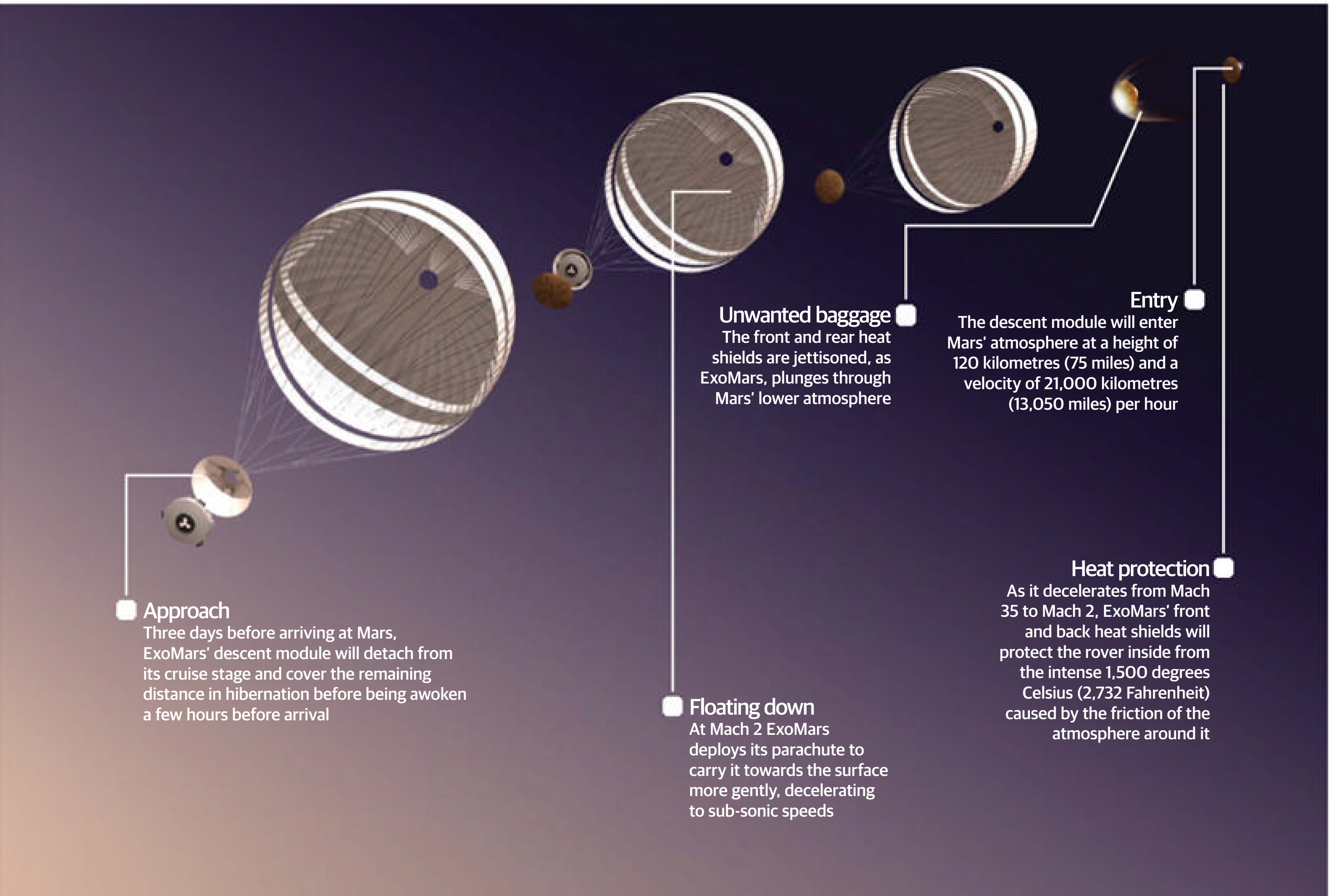
Our planet sits within the Sun's habitable zone - a thin ring of possible orbits that yields temperatures suitable for liquid water. Although not all astrobiologists agree, the alien-hunter's mantra is normally 'follow the water'. That has led to the search for alien life being extended beyond our Solar System and the hunt for Earth-like planets circling in the habitable zones of other stars. So far a total of nearly 2,000 confirmed exoplanets have been found, with a handful of them being rocky worlds in the habitable zones of their parent stars. Telescopes due to be launched in the next decade will be equipped with exquisite instrumentation capable of probing the atmospheres of these Earth-like alien worlds for signs of life. However, that doesn't mean the search is over in our own Solar System. Venus and Mars are only two of the places where life might exist, as water can be found far outside of the habitable zone too.

Given that water covers two thirds of our planet's surface, you might be forgiven for thinking Earth is the wettest place in the Solar System, but it isn't. That accolade goes to Europa, one of Jupiter's clan of 67 moons. Despite being smaller than our Moon, it is home to around twice the amount of water stored in all of Earth's oceans, lakes, seas and rivers. This water remains liquid despite being over 750 million

Sequence of events: The touchdown of ExoMars

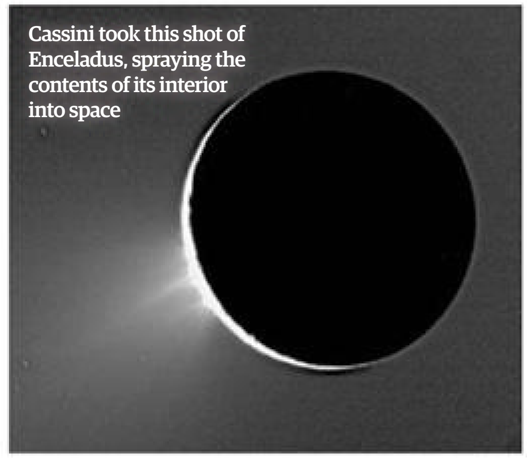
In order to land safely on the Red Planet, the 2018 rover needs to carry out a series of manoeuvres

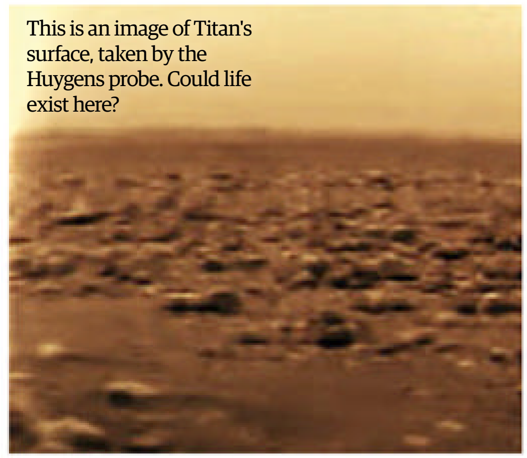




The ExoMars rover, shown here as a prototype, will drill into the surface of the Red Planet in the search for life


The Crybot is a probe that can penetrate kilometres-deep ice crusts to explore what's lying the oceans below


Cassini took this shot of Enceladus, spraying the contents of its interior into space


This is an image of Titan's surface, taken by the Huygens probe. Could life exist here?

kilometres (466 million miles) from the Sun – more than three times further away than the outer edge of the habitable zone. It's not our star keeping the water warm at this otherwise frigid distance, but Jupiter. Europa orbits the giant planet in just three and a half days and is mercilessly pummelled by Jupiter's immense gravity as it goes. This gravitational flexing injects enough energy into the moon's core to maintain a sizeable ocean of liquid water. The colossal gravitational tidal forces it experiences means Europa's subsurface ocean can rise and fall by as much as 500 metres (1,640 metres). The ocean is shielded from the vacuum of space by vast sheets of ice, which sport gaping cracks called lineae, caused by the Europan ocean sloshing around beneath it and cracking it up.

Any life existing in the subterranean water would be hidden away from what little solar energy reaches this part of the Solar System. That isn't necessarily a problem, because life has been found deep in our own oceans receiving no sunlight whatsoever. Instead, its energy supply is the stream of minerals seeping out of cracks in the Earth's crust on the ocean floor. Tidal heating by Jupiter may cause similar hydrothermal vents on Europa's seabed and there could even be a supply of oxygen too. One study suggests that cosmic rays hitting the surface of the ice could split some of the water into oxygen and hydrogen, some of which could end up in the cracks and filter down into the ocean below. Some questions need answering first, however. "It all depends on how thick that ice is and at the moment we simply don't know," says Dartnell. The presence of so much liquid water has led to numerous calls for scientists to send a mission to land on the ice and explore. While no such lander is currently planned, ESA hopes to launch the Jupiter Icy Moons Explorer (JUICE) in 2022 with the intention of flying close to Europa.

"It's unclear whether liquid methane can be as effective a solvent for structures like DNA as water is on Earth"

Dr. Lewis Dartnell

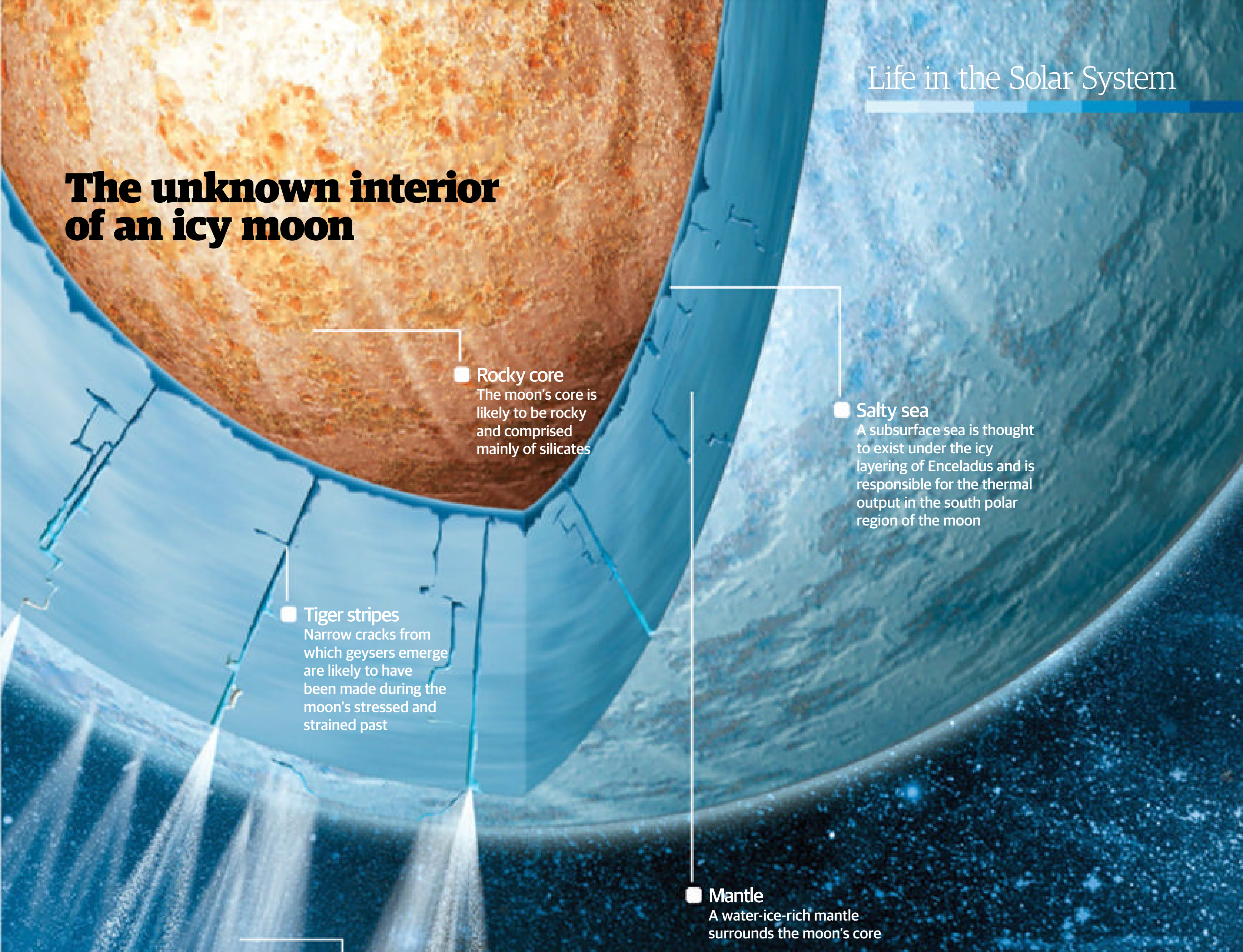
The only mission to have done that so far is the Galileo probe, launched in 1989. Ever since, the small moon has commanded the lion's share of attention when it comes to habitable moons in our Solar System. But of late an even smaller, more-distant satellite – Saturn's Enceladus – has been quietly climbing the list. In 2005, the Cassini probe caught the moon spewing water plumes into space from its south pole. The water seems to be coming from four giant fissures in the moon's surface known as tiger stripes, which have been named Baghdad, Cairo, Alexandria and Damascus. Over a hundred such fountains have since been identified and it's thought that together they eject water at the rate of 200 kilograms (440 pounds) each second.

Results published by the Cassini team suggest these jets are coming from an ocean of water tucked away under the moon's icy crust. "There is enough water there to fill Lake Superior here on Earth," says lead author Luciano Iess from the Sapienza University of Rome. So, could such an ocean be home to life? "I think Europa is a better bet than Enceladus," says Dartnell. "But Enceladus is easier to sample." As Enceladus throws some of its water into space, it's easier to access than the ice-shrouded ocean on Europa. Missions could fly through the Enceladean plumes and collect material, even returning it to Earth for detailed analysis, whereas sampling the Europan ocean would require manoeuvres.

Landing a spacecraft on the surface of an object in the outer Solar System is no mean feat. In fact, it has only been tried once before: in January 2005, the Huygens probe settled down on the surface of Titan. Saturn's largest moon and the second largest in the Solar System, Titan is bigger than the planet Mercury and it's also the only moon known to have a thick atmosphere. Like Venus, that atmosphere makes observations of the surface very difficult, so Huygens was sent through the clouds to investigate. Its findings have implications for the chances of finding life there.

Like Earth, Titan plays host to lakes, rivers and seas. It has islands, coastlines and archipelagos, yet this intricate system is not sculpted by liquid water,

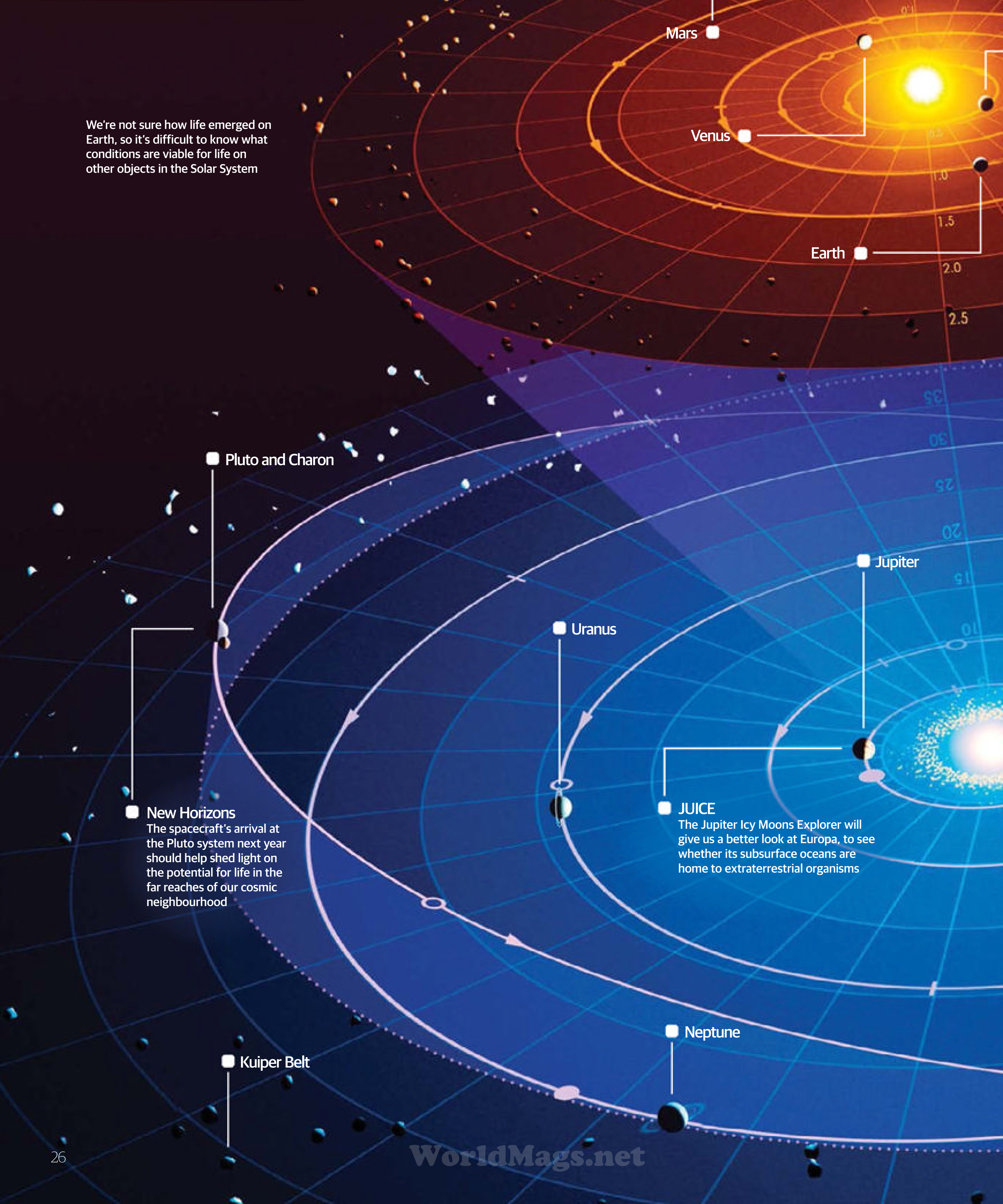
The unknown interior of an icy moon

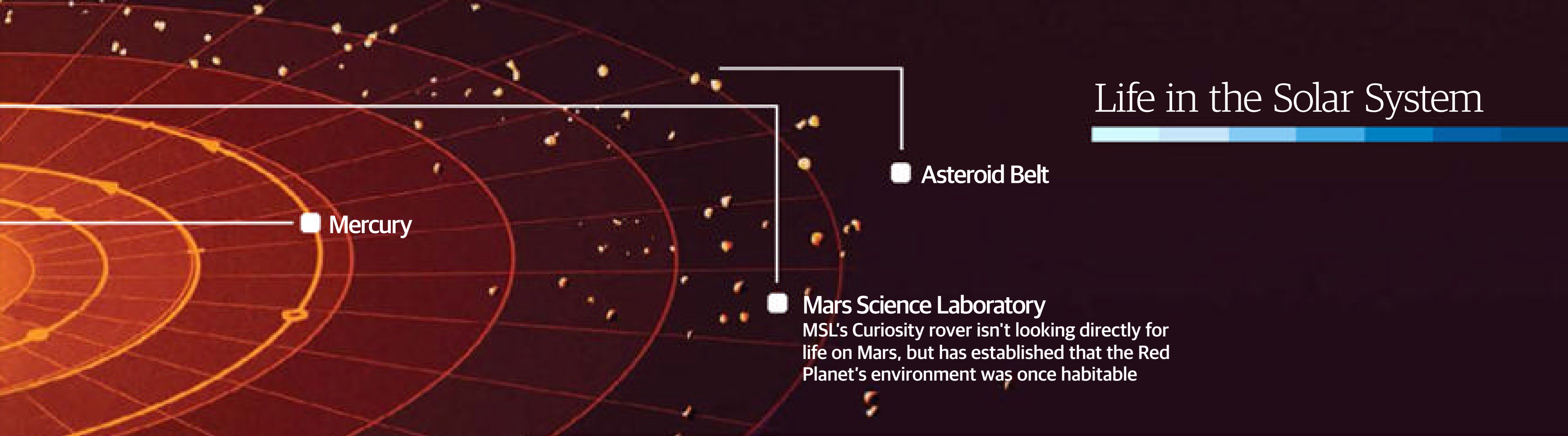


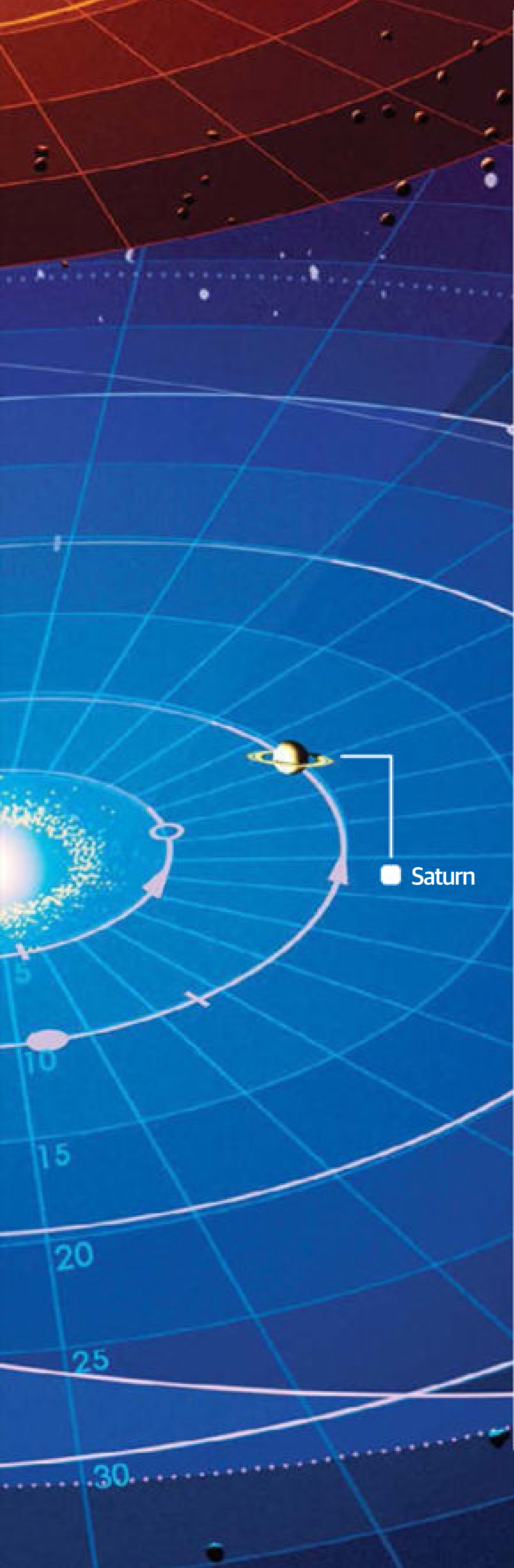

Saturn's Enceladus, a moon of icy volcanic flows commonly known as geysers, is one of the worlds astronomers are targeting when it comes to looking for life

Life in the Solar System

We're not sure how life emerged on Earth, so it's difficult to know what conditions are viable for life on other objects in the Solar System







"We still have a lot of work to do in order to understand what makes a suitable habitat for life"

but by liquid methane, which rains down to the surface as water does on Earth. Hydrocarbons – the building blocks from which life is constructed – have also been spotted. However, it remains to be seen if life can develop under such alien circumstances. "It's unclear whether liquid methane can be as effective a solvent for structures like DNA as water is on Earth," says Dartnell.

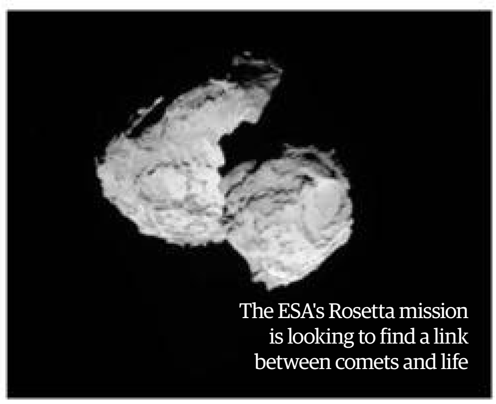
Titan still has liquid water – it just isn't on the surface. In July 2012, scientists using five years' worth of Cassini data found evidence that the moon probably has a sub-surface ocean comprised of liquid water and ammonia. It's thought this reservoir is incredibly salty, perhaps as salty as the Dead Sea here on Earth. But once again extremophiles have shown us that life can adapt to high salinity, particularly if the water was less salty in the past. "It would make Titan a unique place, perhaps with not one biosphere, but two," says Dartnell. If this is the case, it is possible that these two ecosystems could have developed entirely independently of each other.

If chemicals other than water are being considered as solvents capable of sustaining life, another world to look at might be Triton – Neptune's largest moon. The temperature here plummets to just -235 degrees Celsius (-391 Fahrenheit), too cold even for methane to remain liquid. However, it's believed that an ocean exists beneath its icy crust. Ice volcanoes on the surface eject what scientists believe to be liquid nitrogen and methane. Hydrocarbons are thought to exist here too, although that might not be enough to make the moon habitable. "Triton is the outside bet because no one knows if liquid nitrogen can sustain life," says Dartnell.

What makes Triton particularly interesting is that it's the only sizeable moon in the Solar System to orbit its planet backwards – in the opposite direction to the spin of its host. It's very hard to envisage how such a big moon could have formed spinning backwards around its planet, so the leading theory is that Triton was captured by Neptune's gravity some time after the planet formed. The moon's most likely birthplace is the Kuiper Belt – an area of icy bodies that includes the dwarf planet Pluto. This region is home to at least twenty times more material than the Asteroid Belt between Mars and Jupiter. Beyond the Kuiper Belt sits the scattered disc – the origin of short-period comets such as the famous Halley's comet. Studies of both comets and asteroids have shown that they contain complex organic molecules that might be capable of acting as the building blocks for life. Missions like ESA's Rosetta – which linked up with comet 67P/Churyumov-Gerasimenko after a ten-year, 400-million-kilometre (250-million-mile) journey – hope to discover more about the link between comets and life.

During the Solar System's youth, its planets and moons were battered by a deluge of comet and asteroid impacts over an era known as the Late Heavy Bombardment period. Objects like Mercury and the Moon still bear the scars of these collisions today. It's possible that they even seeded the infant Earth with the right range of chemicals from which life would later develop. If that is true, then it's very likely other places in our Solar System were seeded too. The answer to the question of whether those seeds turned into living organisms elsewhere has been the driving force behind much of our exploration of our local space neighbourhood so far, and will continue to be in future.

However, our searching to date has shown that we still have a lot of work to do in order to understand what makes a suitable habitat for life. Earth is still the only place we know of capable of supporting living things, yet we still don't even know for sure how life on our planet began. Knowing what turned a set of inanimate chemical ingredients – possibly delivered by comets – into something we'd describe as living, would be a big step in determining whether that has happened on other worlds, both in our Solar System and even beyond. ■

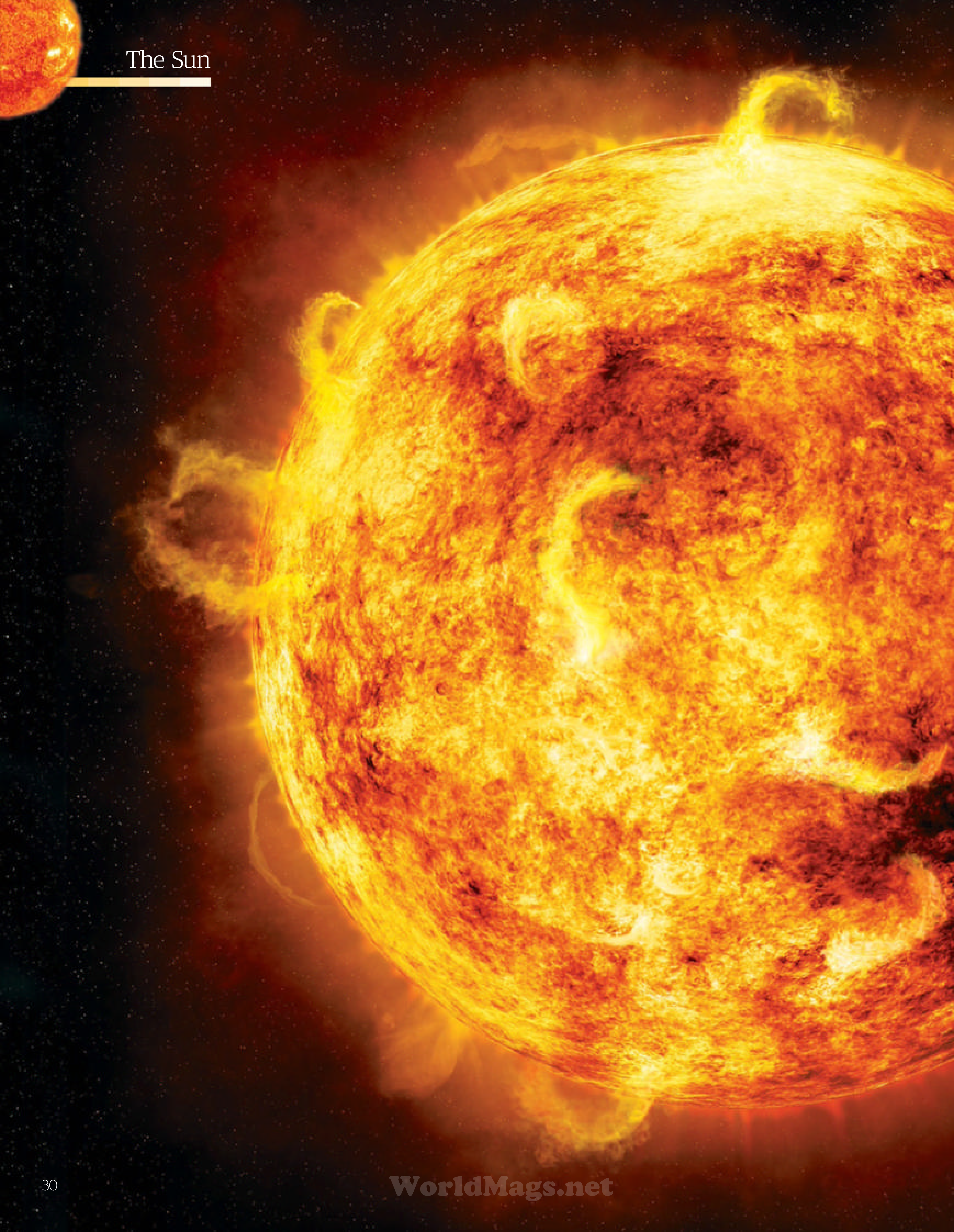

The ESA's Rosetta mission is looking to find a link between comets and life

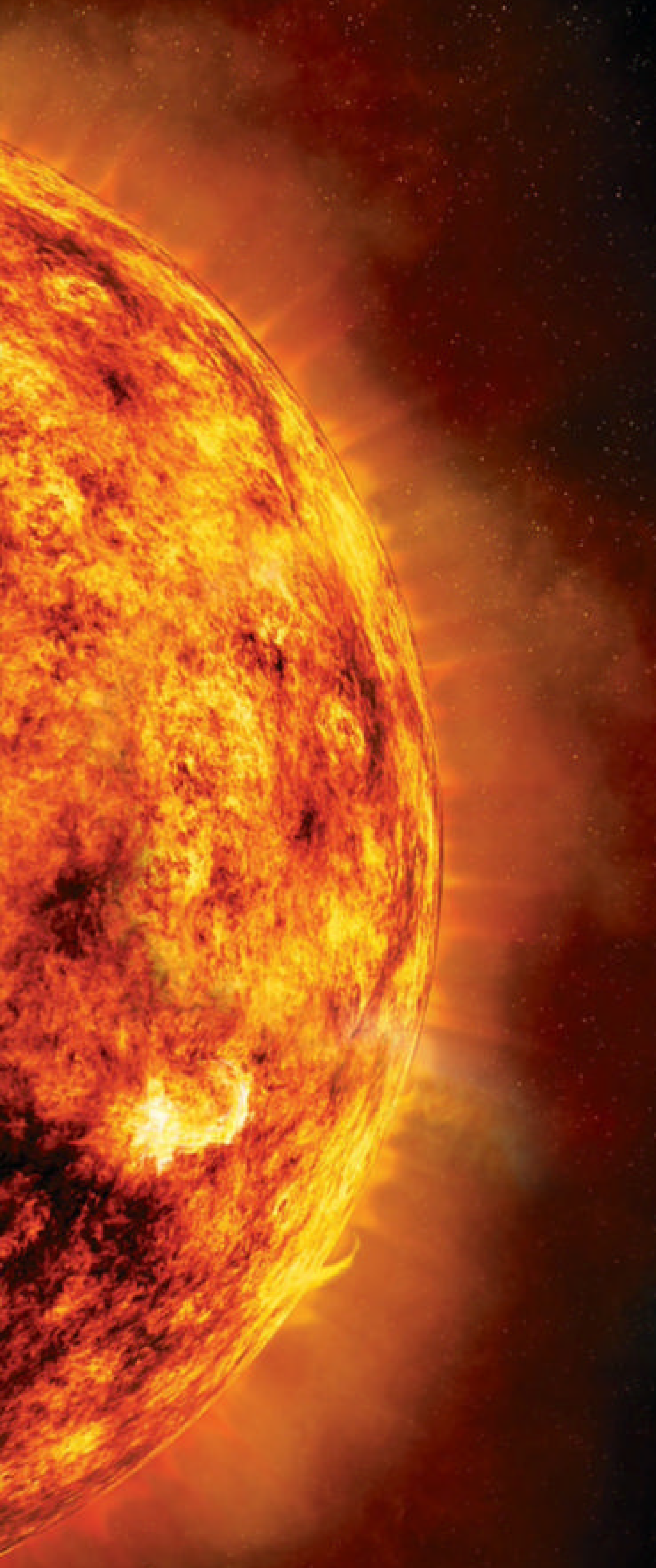
The Sun

Discover the star at the centre of our Solar System

“A solar flare is a sudden increase in the brightness on the surface of the Sun”

Thinkstock





All About... THE SUN

The vast nuclear furnace that we know as the Sun is responsible for dictating the seasons, climate and characteristics of every planet in the Solar System. Here, we take an in-depth look at this source of power that has astounded humanity since the dawn of existence

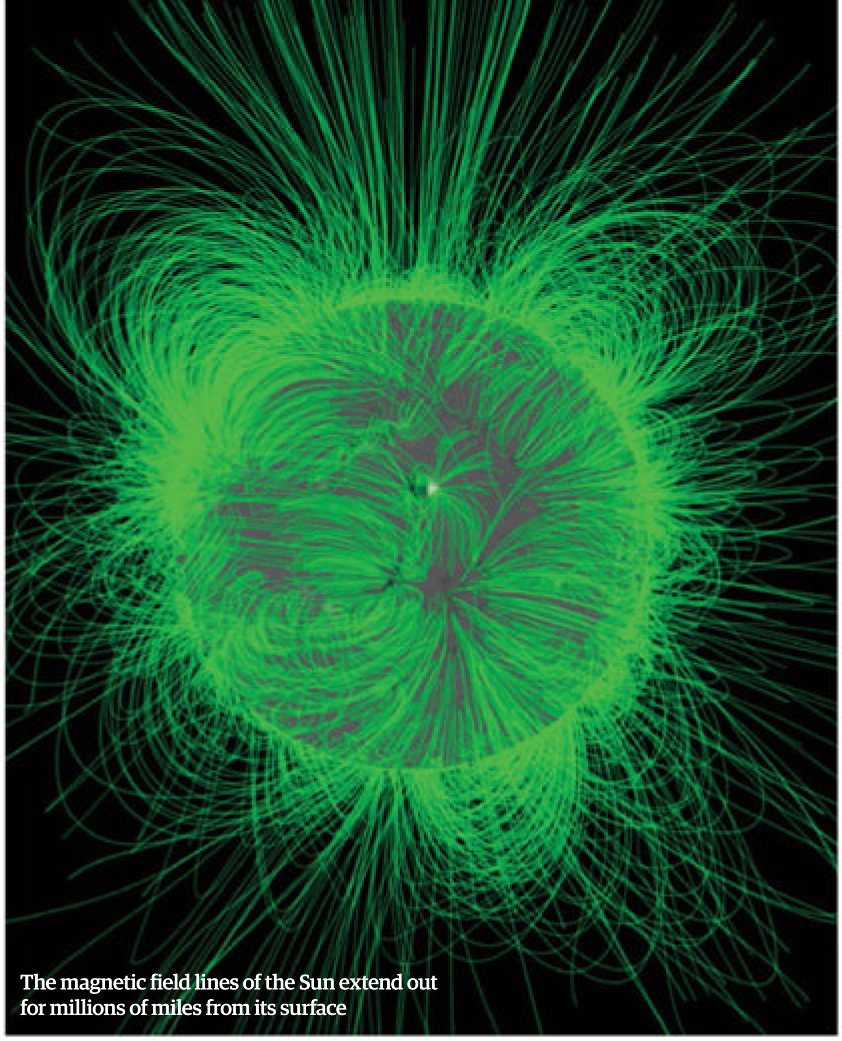
At about 150 million kilometres (93 million miles) from Earth lies a giant incandescent ball of gas weighing in at almost 2,000 trillion trillion kilograms and emitting power equivalent to 1 million times the annual power consumption of the United States in a single second. Since the dawn of Earth, 4.6 billion years ago, it has been the one ever-present object in the sky, basking our world and those around us in energy and light - and providing the means through which environments, and ultimately life, can flourish. We see it every day and rely on its energy to keep our planet ticking, but what exactly is this giant nuclear reactor at the centre of the Solar System that we call the Sun?

Over 5 billion years ago, a vast cloud of dust and gas was located where our Solar System is now. Inside this nebula something huge was happening; gravity was pulling together the debris, likely the remnants of another star going supernova, into one central mass. As the various metals and elements were brought together, they began to fuse into an object at the heart of this nebula. This dense clump of matter, called a protostar, grew and grew in size until it reached a critical temperature due to friction, about 1 million degrees Celsius (1.8 million degrees Fahrenheit). At this point. nuclear fusion kicked in and our Sun was born.

At the heart of the Sun, hydrogen atoms fused together to produce helium, releasing photons of light in the process, which extended throughout the Solar System. Eventually the hydrogen and helium atoms began to fuse and form heavier elements such as carbon and oxygen, which in turn formed key components of the Solar System, including humans. To us, it's the most important object in the sky. An observer watching from afar, however, would see no discerning qualities of our star that would make it stand out from any of the other hundreds of billions of stars in the Milky Way. In the grand scheme of things it's a fairly typical star that pales in comparison to the size of others. For instance, Sirius, the brightest star in the night sky, is twice as massive as the Sun and 25 times more luminous, while Arcturus, the fourth brightest object in the night sky, is almost 26 times the size of our closest star.

The Sun is located at a mean distance of 150 million kilometres (93 million miles) from Earth, a distance known as one astronomical unit (1 AU). This giant nuclear furnace is composed mostly of ionised gas and drives the seasons, ocean currents, weather and climate on Earth. Over a million Earths could fit inside the Sun, which is itself held together by gravitational attraction, resulting in immense pressure and temperature at its core. In fact, the core reaches a temperature of about 15 million degrees Celsius (27 million degrees Fahrenheit), hot enough for thermonuclear fusion to take place. The intense physical process taking place in the Sun produces heat and light that radiates throughout the Solar System. It's not a quick process, though. It takes more than 170,000 years for energy from the core to radiate outwards towards the outer layers of the Sun.

Our Sun is classified as a yellow dwarf star, and these stars range in mass from about 80 per cent to 100 per cent of the mass of the Sun, meaning our star is at the upper end of this group. There are also three further groups into which stars are classified: Population I, II and III. Our Sun is a Population I star, which denotes that it contains more heavy elements compared to other stars (although still accounting for no more than approximately 0.1 per cent of its total mass). Population III stars are those that formed at the start of the universe, possibly just a few hundred million years after the Big Bang, and they are made from pure hydrogen and helium. Although hypothesised, no such star has ever been found, as the majority of them exploded as supernovae in the early universe, and led to the formation of Population I and II stars, the latter of which are older, less luminous and colder than the former.


The magnetic field lines of the Sun extend out for millions of miles from its surface

By now you're probably thinking our Sun is insignificant, but that's anything but the case. Being our closest star, and the only one we can study with orbiting telescopes, it acts as one of the greatest laboratories available to mankind. Understanding the Sun allows us to apply our findings to research here on Earth, such as nuclear reactors, and our observations of distant stars. Over the next few pages we'll delve into the reasons why studying the Sun is so important and explore some of the amazing physics going on inside and outside this vast nuclear furnace.

> "The core reaches a temperature of about 15 million degrees Celsius, hot enough for thermonuclear fusion to take place"

The planets in relation to the Sun

All figures = million miles from Sun

Spicules
These supersonic jets of hot plasma form in the Sun's interior and rise to a height of around 5,000km (3,000 mi) above the Sun's photosphere

Coronal Mass Ejections
A Coronal Mass Ejection (CME) is a burst of plasma and magnetic fields, known as stellar wind, being thrown into space from the Sun's corona

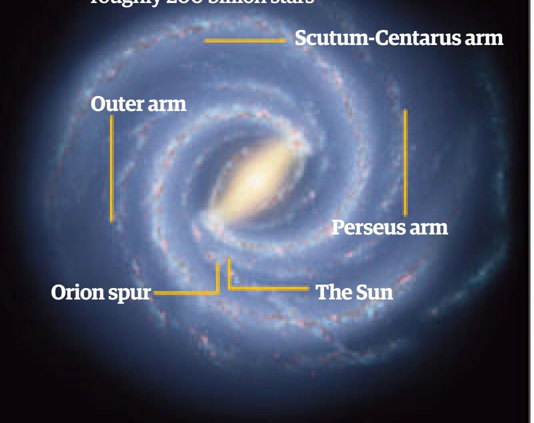
Faculae
Produced by concentrations of magnetic field lines, these bright spots appear on the Sun's chromosphere in regions where a sunspot will form

Granulation
The Sun often appears granulated in images because of convection currents in its photosphere and chromosphere

Prominences
These large loops of energy extend outwards from the Sun's corona. They can range over 700,000km (430,000 mi), approximately the radius of the Sun

Sunspot
These dark spots on the surface of the Sun are caused by intense magnetic fields and are usually accompanied by a solar flare or CME

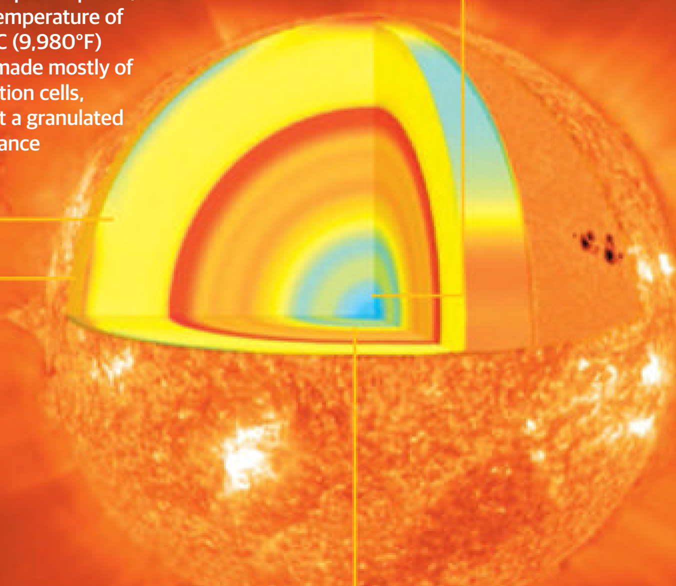
Our Solar System is located in the outer reaches of the Milky Way galaxy, which has roughly 200 billion stars



Layers of the Sun

Photosphere
The visible surface of the Sun, the photosphere, has a temperature of 5,530°C (9,980°F) and is made mostly of convection cells, giving it a granulated appearance

Inner core
Most of the Sun's fusion power is generated in the core, which extends outwards from the centre to about a quarter of the Sun's radius



Corona
The outer 'atmosphere' of the Sun. It is made of plasma, extends millions of kilometres outwards and has a higher temperature than the inner photosphere

Chromosphere
This thin layer about 2,000km (1,240 mi) thick sits just above the photosphere and is the area where solar flares and sunspots are visible

Radiative zone
This area is full of electromagnetic radiation from the core that bounces around as photon waves. It makes up about 45 per cent of the Sun

Solar storms

Like the Earth, the Sun has an atmosphere, but the two are very different. The Sun's can be incredibly volatile with powerful magnetic activity that causes phenomena referred to as solar storms here on Earth

Solar storms are violent outbursts of activity on the Sun that interfere with the Earth's magnetic field and inundate our planet with particles. They are the result of outpourings of energy from the Sun, either in the form of a Coronal Mass Ejection (CME) or a solar flare. The former is a release of a large amount of material, mostly plasma, from the Sun, while the latter is a sudden release of electromagnetic radiation commonly associated with a sunspot. While no direct connection has been found between CMEs and solar flares, both are responsible for causing solar storms on Earth. The reason why these two events occur is due to the Sun's atmosphere and its turbulent interior, with all of its components playing a part in bathing our planet in bursts of energy.

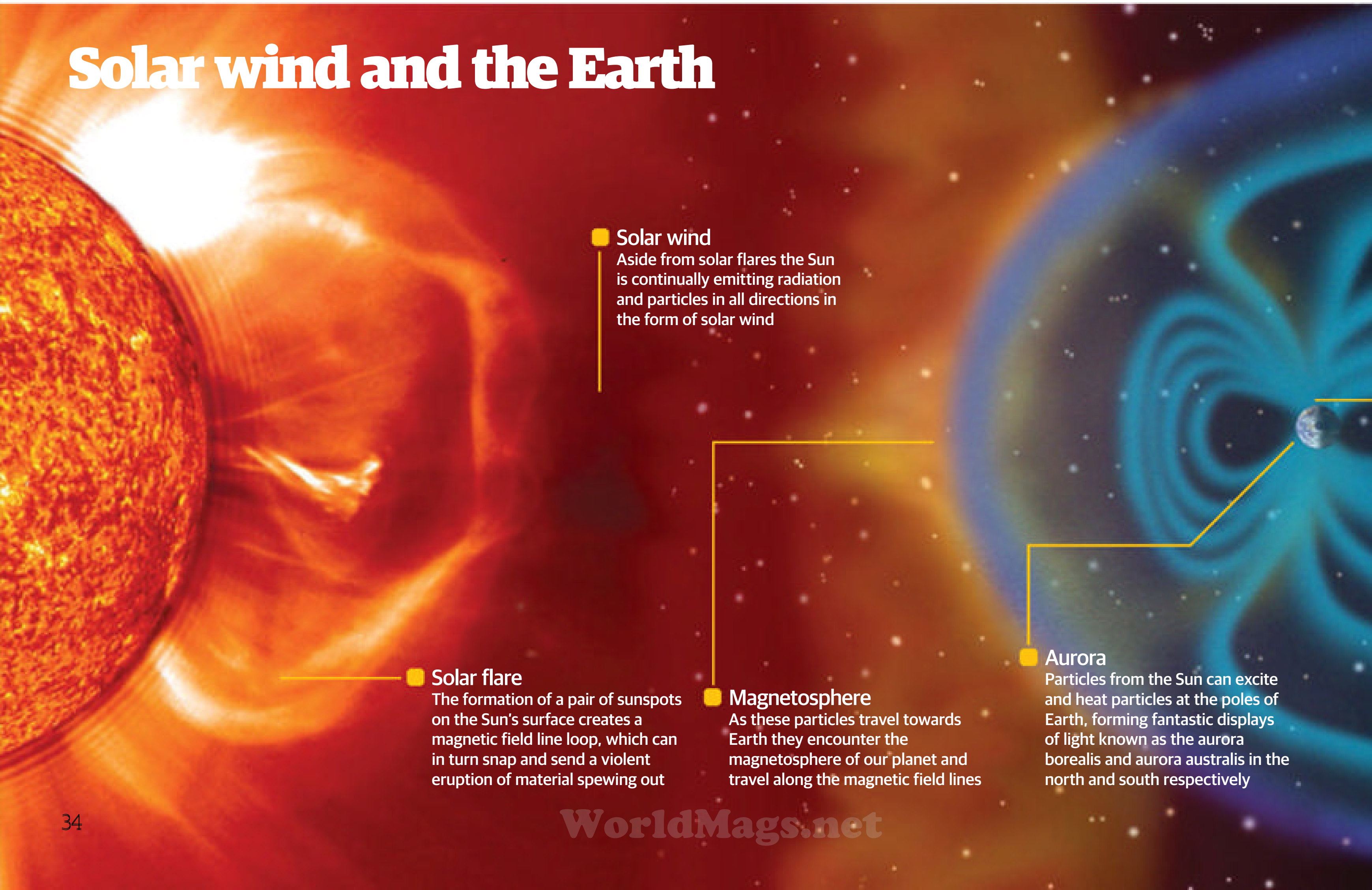
The lowest part of the atmosphere, the part directly above the Sun's radiative zone, is the photosphere. This is the visible part of the Sun, which is 300-400 kilometres (180-240 miles) thick and has a temperature of about 5,530 degrees Celsius (9,980 degrees Fahrenheit). This produces a white glow, although from Earth this usually appears yellow or orange due to our own atmosphere.

As you travel through the photosphere, away from the Sun's core, the temperature begins to drop and the gases become cooler, in turn emitting less light. This makes the photosphere appear darker at its outer edges and gives the Sun an apparently clearly defined outer boundary, although this is certainly not the case as the atmosphere extends outwards much further.

Once you pass through the photosphere you enter the chromosphere, which is about 2,000 kilometres (1,240 miles) thick. Here the temperature rises to about 9,730 degrees Celsius (17,540 degrees Fahrenheit). The reason for this is that the convection currents in the underlying photosphere heat the chromosphere, producing shock waves that heat the surrounding gas and send it flying out of the chromosphere as tiny spikes of supersonic plasma known as spicules.

The final layer of the Sun's atmosphere is the corona. This huge expanse of material can stretch as far

Solar wind and the Earth



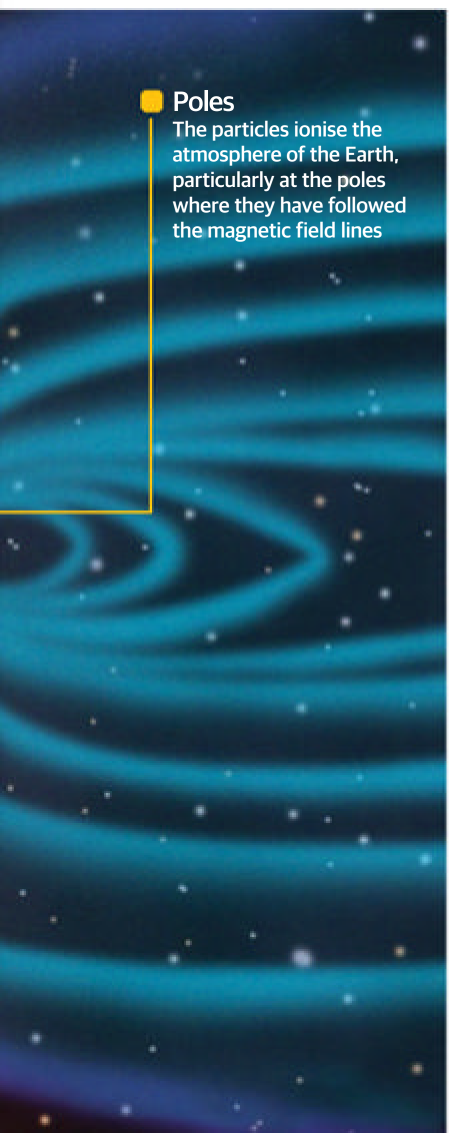
Particles ejected from the Sun can cause fantastic light displays at Earth's poles, known as the aurora borealis (or Northern Lights) and the aurora australis (or Southern Lights)

"Once you pass through the photosphere you enter the chromosphere, which is about 2,000km thick"

as several million miles outwards from the surface. Oddly, the temperature of the corona averages a whopping 2 million degrees Celsius (3.6 million degrees Fahrenheit). The reason for this is unknown. As far as we are aware, atoms tend to move from high to low temperatures and not vice versa, so the process of material moving out of the Sun beyond the photosphere is not understood.

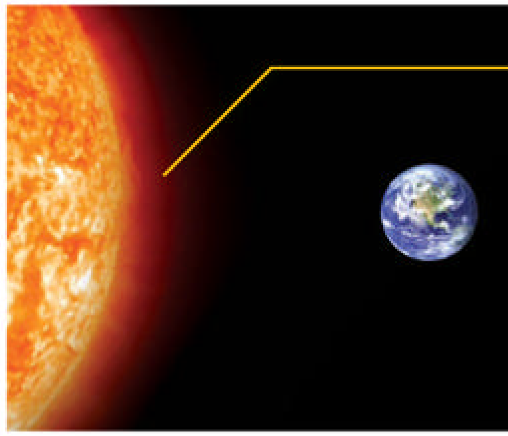
On the photosphere, dark and cool regions known as sunspots appear in pairs as a result of intense magnetic fields. The magnetic fields, caused by gases moving in the Sun's interior, leave one sunspot and enter another. Sunspot activity rises and falls in an 11-year cycle, as discussed in the next section. Sometimes clouds of gases from the chromosphere will follow these magnetic field lines in and out of a pair of sunspots, forming an arch of gas known as a solar prominence. A prominence can last up to three months and may extend up to 50,000 kilometres (30,000 miles) above the surface of the Sun. Once they reach their maximum height they break and erupt, in turn sending massive amounts of material racing outwards through the corona. This is an event known as a Coronal Mass Ejection (CME).

When the sun's magnetic field is concentrated in sunspot areas, the resultant magnetic field lines can extend and snap, causing a violent explosion on the surface of the Sun called a solar flare. At the moment of eruption, vast amounts of radiation are emitted into space, which we call a solar storm when it reaches Earth. The particles within a solar storm often interact with particles in the atmosphere of planets in the Solar System, causing fantastic displays of light at their poles as the gases in the planet's atmosphere are heated by the particles. On Earth we know these as the aurora borealis in the Northern Hemisphere and the aurora australis in the Southern Hemisphere.

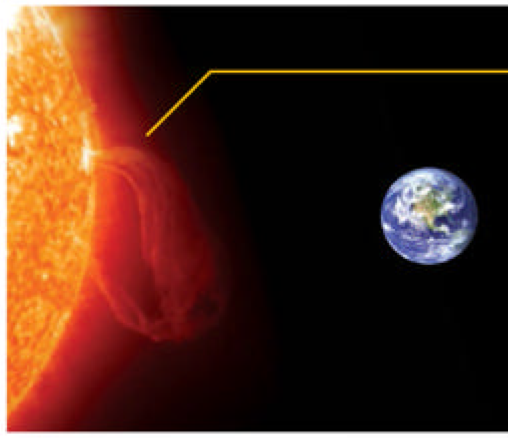


How solar storms work

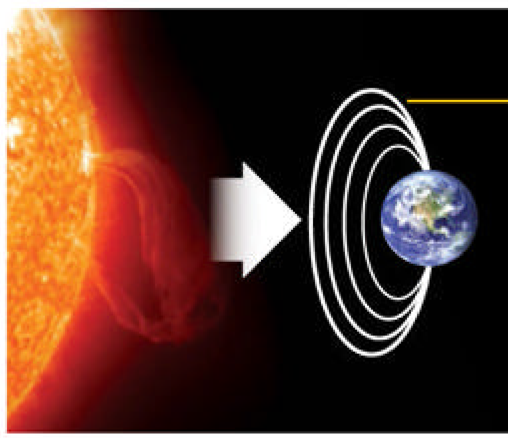
Vast amounts of radiation heading for Earth



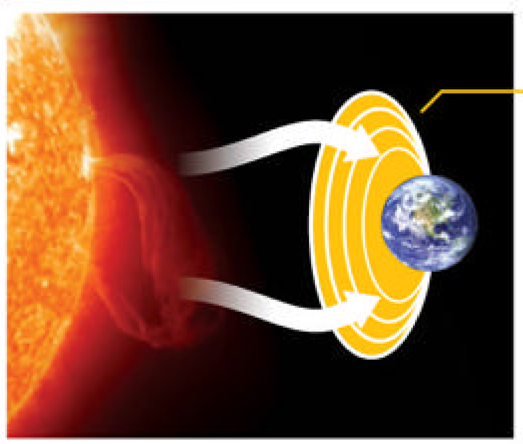
Explosion
A solar flare can release up to 6x10^25 joules of energy as it explodes from the surface of the Sun. The giant clouds of radiation and particles can take up to two days to travel to the Earth



Cycle
Solar flares peak in 11-year-long activity cycles. The cause of these cycles is unknown. In periods of inactivity there can be less than one flare a week, but when the Sun is at its busiest there can be several every day



Intensity
Solar wind typically travels at 1.6 million kph (1 million mph), but the explosive event that emits a solar flare can send it hurtling towards the Earth up to four times faster



Magnetosphere
The magnetic field surrounding the Earth acts as a barrier from the Sun's activity, but some of the particles travel along the magnetic field lines and excite particles in our atmosphere, in turn causing auroras to form at the poles

The solar cycle

Our Sun is ever-changing, affecting all life on Earth and our natural environment

Our Sun may be a great distance away, but its fluctuations and perturbations are still felt here on Earth.

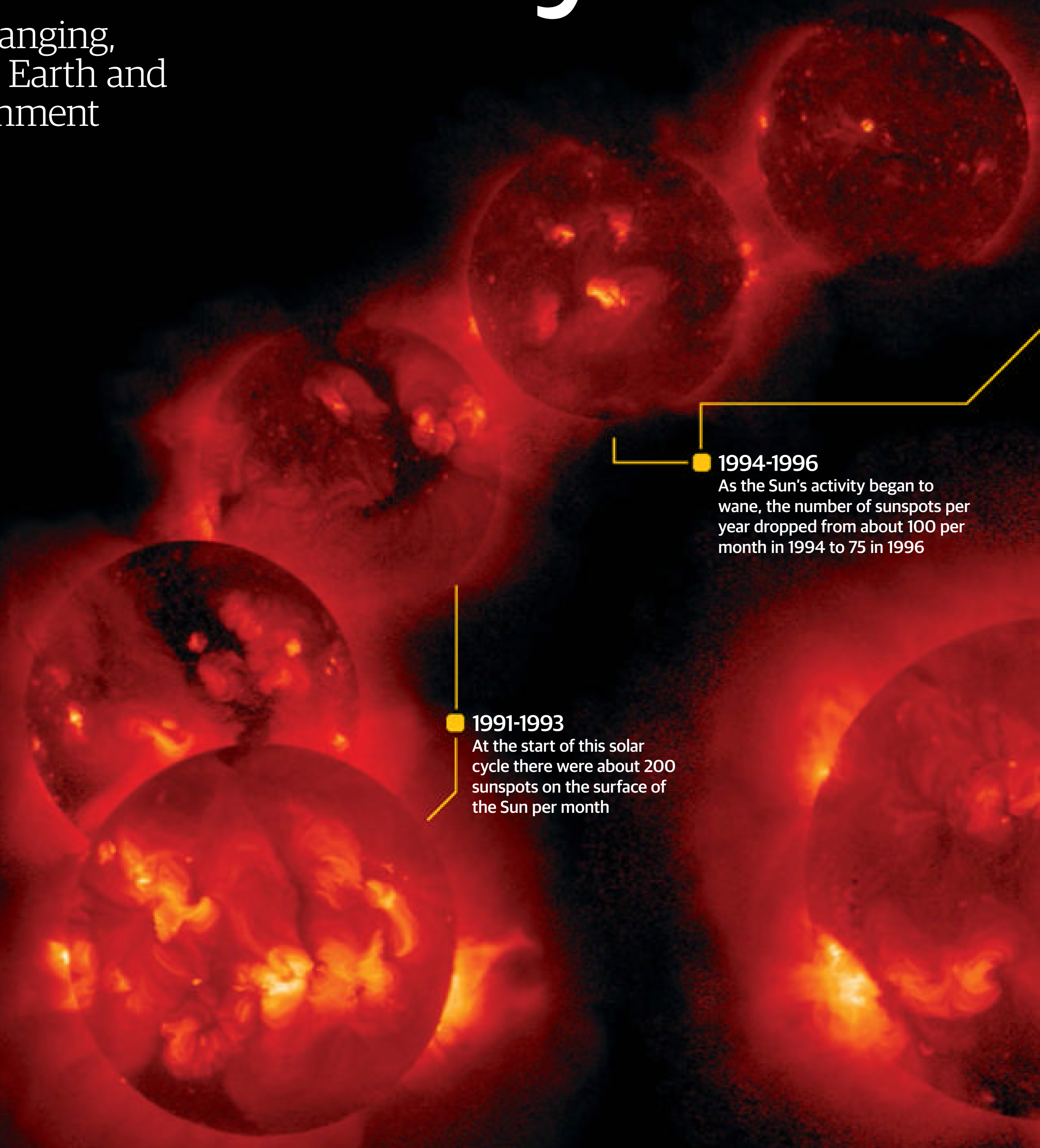
Every 11 years the Sun moves from a period of low activity, known as a solar minimum, to a period of high activity, known as a solar maximum, and back again. When it is at its most active, the Sun is even more violent than usual, with a greater number of sunspots appearing on its surface, and therefore more solar flares emitted into space. During its minimum point it is still a raging inferno firing material into space but, by comparison, it is much quieter and sunspots, and therefore solar storms, are rare.

Cycles are observed by monitoring the frequency and position of sunspots on the Sun. When the Sun reaches the end of its cycle, new sunspots will appear near the equator. The beginning of the next cycle will see sunspots appear at higher latitudes on the surface of the Sun.

Solar cycles have been observed for centuries, but a standardised method of counting them was not devised until 1848 when Johann Rudolf Wolf started counting sunspots on the solar disk and calculated the Wolf number, which is still used today to keep track of the solar cycle. From 1645 to 1715 there were few sunspots present on the Sun, a period known as the Maunder Minimum.

The number of sunspots has been relatively more uniform this century, with cycles having an average period of 10.5 years. The Sun also has a 22-year magnetic cycle where, every 22 years, its magnetic field flips from pole to pole. This doesn't have a noticeable effect on the Solar System, but indicates when the solar maximum of the current cycle has been reached.

However, the reason behind these cycles remains a mystery, and no one yet has any clear understanding as to why the Sun has these periods of varying activity.



10 years of the Sun

These X-ray images were taken by Japan's Yohkoh Solar Observatory and show the changes in the Sun's corona over a ten-year cycle between 30 August 1991 and 6 September 2001

"Solar cycles have been observed for centuries, but a method of counting them was not devised until 1848"

1997-1998
The Sun reached its period of solar minimum between these years, falling to almost zero sunspots per month

1999-2001
The Sun's activity increased again to a solar maximum, with up to 175 sunspots appearing per month

The Scientist's view

How we understand solar cycles

"Sun-Earth interaction is complex, and we haven't yet discovered all the consequences of solar cycle variation on Earth's environment. We saw a large amount of geomagnetic activity driven by recurring fast solar wind streams during the recent solar minimum. A surprising departure from the consistently low activity we'd come to expect from previous minima, especially considering the record low level of sunspots. These new observations deepen our understanding of how solar quiet intervals affect the Earth and how and why this might change from cycle to cycle."

Sarah Gibson, UCAR, @AtmosNews

The Sun in numbers

Fantastic figures and surprising statistics about our nearest star

99.86%
The Sun's percentage of mass of the entire Solar System

Less than 5% of stars in the Milky Way are brighter or larger than the Sun

1 million Earths
Would fit inside the Sun

164 watts *Is the amount of energy every square metre of the Earth's surface receives. That's the equivalent of a 150-watt table lamp on every square metre of the Earth's surface*

498 seconds
How long it takes light to travel from the Sun

100 BILLION
Tons of dynamite would have to be detonated every second to match the energy produced by the Sun

The SOHO mission

The Solar and Heliospheric Observatory was launched in December 1995 and is helping us explore the Sun

Interview

SOHO project scientist Bernhard Fleck tells us why studying the Sun is important to Earth

1. Understand life

"The Sun provides the energy for all life on Earth. It seems quite natural that we are curious to know more about the star from which we live."

2. Understand climate

"Solar radiation is the dominant energy input into the terrestrial ecosystem. The Sun provides a natural influence on the Earth's atmosphere and climate. To understand mankind's roles in climate change, the Sun's impact must be understood."

3. Predict space weather

"Our Sun is very dynamic and produces the largest eruptions in the Solar System. These solar storms can reach our planet and adversely affect technologies such as satellites and power grids. Space weather becomes increasingly important as our society depends more on modern technologies."

4. Learn about stars

"If we want to understand the universe, we have to understand the evolution of galaxies. To understand galaxies, we need to understand the evolution of stars that make up the galaxies. If we want to understand stars, we better understand the Sun, the only star we can resolve in great detail."

5. Stellar physics lab

"The Sun lets us study basic physical plasma processes under conditions that can't be reproduced on Earth."

The Solar and Heliospheric Observatory, also known as SOHO, was launched on 2 December 1995. It was built in Europe by prime contractor Matra Marconi Space, which is now EADS Astrium. The spacecraft is operated jointly by the ESA and NASA. It studies the Sun in depth, all the way from its deep core to its outer corona and its solar wind.

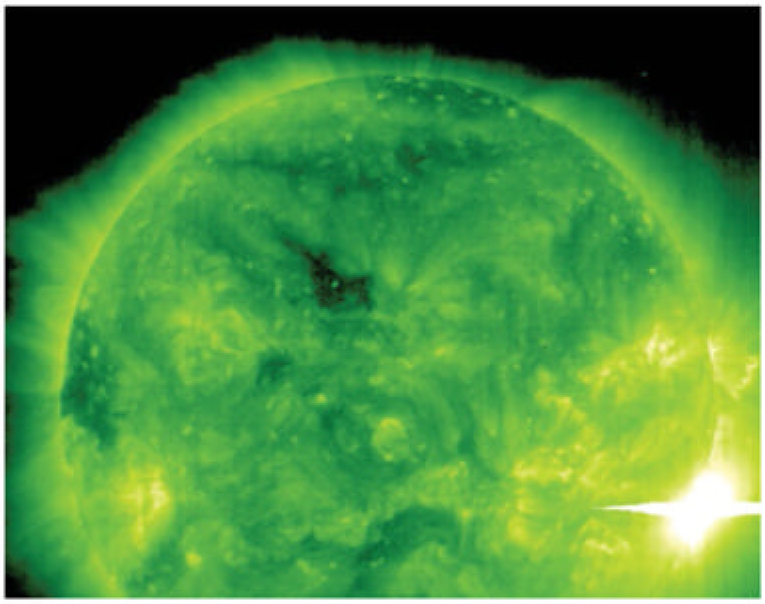
SOHO is made of two modules, the Service Module and the Payload Module. The former provides SOHO with power, while the latter houses all of the instruments on the spacecraft. Overall, there are 12 instruments on board SOHO, nine of which are run by Europe as well as three from the United States.

SOHO is located near to Lagrangian point 1, which is a point between the Earth and the Sun about 1.5 million kilometres (930,000 miles) from our planet. It is the point where the gravitational attraction of the Sun and the Earth cancel out, so a telescope such as SOHO can remain in a stable orbit to observe the Sun. SOHO is one of the only telescopes currently capable of detecting incoming solar flares that could be potentially hazardous to satellites and other electronics on Earth.

Of the 12 instruments on board SOHO one of the most interesting is the Large Angle and Spectrometric Coronagraph (LASCO), which studies the Sun's corona by creating an artificial solar eclipse. The LASCO instrument has been largely responsible for inadvertently discovering many comets near the Sun, with over 1,800 found to date.

SOHO has three primary objectives that it has been carrying out since its launch. One of these was to investigate the outer regions of the Sun, specifically the corona.

At the moment it is still unknown why the corona is hotter than the photosphere and chromosphere of the Sun, so it is hoped that SOHO might help to provide the answer in the future. SOHO has also been used to observe the solar wind, and also to study the interior structure of the Sun through a process known as helioseismology.



On the scale of solar flares, X-class storms are most powerful. SOHO took this image on November 2003 showing the most powerful ever recorded, which reached X28

Take a tour of SOHO

SOHO is made up of two modules. The Service Module forms the lower portion, while the Payload Module sits above

Payload Module
This sits on top of the Service Module and houses all 12 of the instruments on board the spacecraft

Service Module
The Service Module provides power, telecommunications, thermal control and direction to the spacecraft

Malfunction
In 1998 SOHO suffered a major malfunction that almost rendered it unusable. However, some smart thinking enabled scientists to regain control of the telescope, although it now operates without the help of its gyroscopes, the only three-axis stabilised spacecraft to do so

Mission Profile

Solar and Heliospheric Observatory (SOHO)

Mission dates: 02/12/95-12/12/14

Details: SOHO is a joint project between the ESA and NASA. It was designed to study the origin of the solar wind, the outer atmosphere of the Sun and its internal structure. SOHO has found over 1,800 comets to date and discovered that quakes on the Sun's surface are caused by solar flares. It has also made the most detailed map of features on the solar surface.

Antennas
SOHO transfers data back to Earth at a rate of between 40Kbits/s and 200Kbits/s using its high and low gain antennas

Solar panels
SOHO's only source of energy is from the Sun, but as it is in orbit around it, it has a large supply of energy

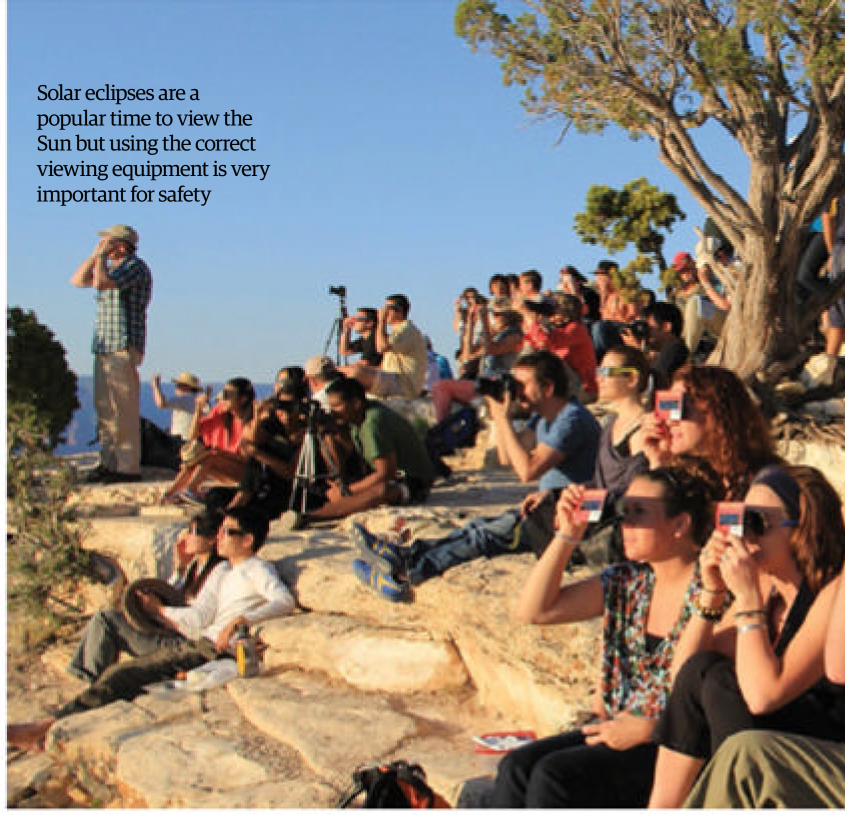
LASCO
SOHO's Large Angle and Spectrometric Coronagraph (LASCO) produces detailed imagery of the solar corona by creating an artificial eclipse

The SOHO spacecraft has survived 17 years in space, 15 more than its initial mission length

"SOHO is located near to Lagrangian 1, which is a point between the Earth and the Sun about 1.5 million km (930,000 mi) from our planet"

Observing the Sun

Humanity has been fascinated by the Sun for thousands of years and even primitive records still prove useful. Discover more about the past, present and future of studying the Sun



Solar eclipses are a popular time to view the Sun but using the correct viewing equipment is very important for safety

Observations of the Sun have been used for both scientific and religious observations for millennia. Civilisations have used the Sun to keep an accurate count of days, months and years since at least 300BC, while scientists such as Galileo studied the Sun through telescopes to discern some of its characteristics.

At the Chankillo archaeological site in Peru can be found the oldest solar observatory in the Americas, a group of 2,300-year-old structures used to track the motion of the Sun known as the Thirteen Towers. These towers provide a rudimentary solar calendar through which the Sun can be traced.

The towers, each between 75 and 125 square metres (807 and 1,345 square feet) in size, run from north to west along a ridge along a low hill. From an observation point to the west of the ridge the Sun can be seen to rise and set at different points along the ridge, which allowed ancient civilisations to track the number of days it takes the Sun to move from tower to tower.

Much later, in 1612, the renowned Italian astronomer Galileo Galilei (1564-1642) used his telescope to make one of the first observations of sunspots on the surface of the Sun. In 1749 daily observations began at the Zurich Observatory and, since 1849, continuous observations have been made to count the number of sunspots present on the Sun's surface at any one time.

Fast forward to today and, aside from SOHO, one of the primary telescopes used to observe the Sun is the Japanese Hinode spacecraft. Hinode is a telescope in sun-synchronous Earth orbit, which allows for nearly continuous observation of the Sun. It was launched on 22 September 2006 and was initially planned as a three-mission study of the magnetic fields of the Sun, but its mission has since been extended as it continues to operate nominally.

Another important Sun-observing telescope is the Solar Dynamics Observatory (SDO), launched by NASA in 2010. The goal of the SDO is to study the influence of the Sun near Earth, predominantly how the Sun's magnetic field is responsible for the solar wind once it is released into the heliosphere. It should help scientists further understand the Sun's influence on the Solar System.

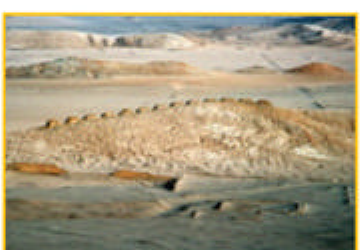
In the future, NASA's Solar Probe Plus will be the closest spacecraft to the Sun, approaching to within just 8.5 solar radii (5.9 million km, 3.67 million mi) after its launch in 2018. It will probe the outer corona of the Sun in unprecedented detail, while becoming the fastest spacecraft of all time in the process, at up to 200 kilometres per second (120 miles per second).

Apart from million dollar telescopes, many amateur astronomers around the globe today observe the Sun either for entertainment or educational benefit. Using specially designed glasses, people can look at the Sun from Earth, although caution must be taken to limit time spent looking at the Sun and it should never be looked at with the naked eye. Other methods of solar observation include using a telescope to produce a trace of the Sun, a method similar to that used by Aristotle and his camera obscura in the 4th Century BC. Again, precautions must be taken here, as under no circumstances should the Sun be directly observed through a telescope.

Whatever the method, and whatever the mission, observations of the Sun have been a long tradition and will continue to be so for the foreseeable future. Astronomical events such as planetary transits and solar eclipses provide amateur astronomers with opportunities to see extraordinary solar phenomena, while agencies throughout the world will continue to study the Sun and learn more about how the fantastic star works.

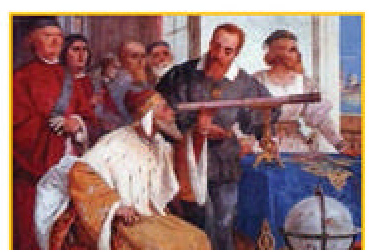
"Civilisations have used the Sun to keep an accurate count of days, months and years since at least 300BC"

The history of observing the Sun



400BC
The world's oldest solar observatory, the Thirteen Towers of Chankillo, is built in Peru to track the motion of the Sun.

350BC
Aristotle uses a camera obscura to project an image of the Sun and observe a partial eclipse.

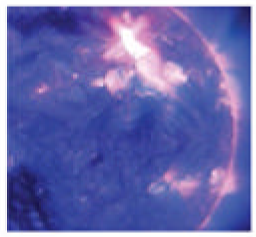


1612
Galileo Galilei uses his telescope to make one of the first observations of sunspots on the surface of the Sun.

A telescope with a digital screen can be used to safely observe the Sun

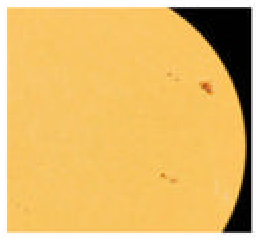
Different ways to observe the Sun

On Earth we perceive the Sun to be a yellow ball of gas in the sky but, like anything as hot as the Sun, it is actually closer to being white hot when viewed from space. There are several telescopes currently observing the Sun but the large majority of our images come from the STEREO telescope and the SOHO observatory, both in orbit around the Sun. By viewing the Sun in different wavelengths we can study its different characteristics and see some of its main features in a different light.



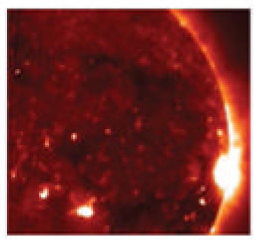
Ultraviolet

Images of the Sun in ultraviolet light are between wavelengths of about 19.5 and 30.4 nanometres. Such an image of the Sun is at the lower end of this scale, and allows us to see where the lower part of the corona and upper part of the chromosphere combine. The light in this image comes from active regions in the Sun's chromosphere.



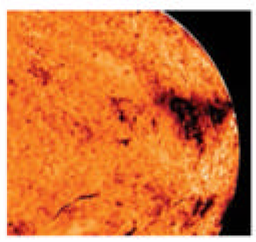
Visible

Visible light images commonly refer to those viewing the Sun in white light, which shows the true colour of the white-hot Sun. In visible light images we can see the Sun's photosphere, which is about 6,000 degrees Celsius (10,832 degree Fahrenheit) and therefore appears white-hot. Here, we can see dark spots on the surface of the Sun, known as sunspots.



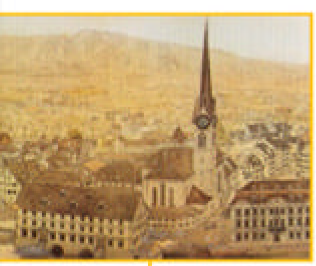
X-ray

Light with a wavelength shorter than ten nanometres (ten billionths of a metre) is known as X-ray light. X-rays are emitted from the Sun's corona, the hottest visible layer of the Sun's atmosphere. The visible areas of brightness are places where more X-rays are being emitted, around areas of increased activity on the Sun's surface.

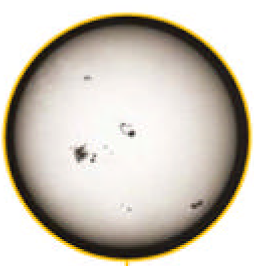


Infrared

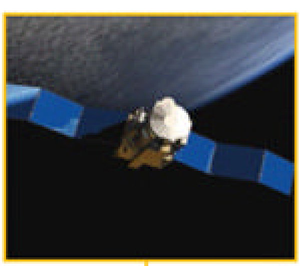
Infrared light is responsible for more than half of the Sun's power output, typically around wavelengths of 1,080 nanometres. Infrared images show features of the Sun's chromosphere and corona. The dark features on the image are areas where the gas is more dense, absorbing more infrared light than in other areas.



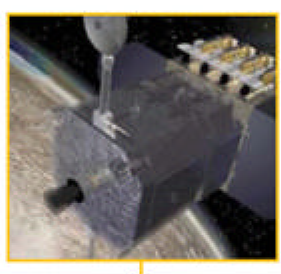
1749
Daily observations of the Sun begin at the Zurich Observatory in Switzerland.



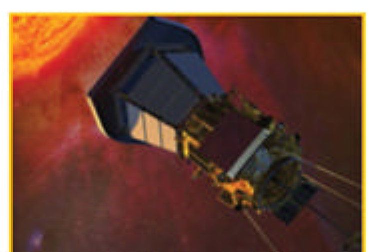
1849
New observatories around the world allow continuous observations of sunspots to be made.



2006
The Japanese telescope Hinode is launched to study the magnetic fields and atmosphere of the Sun.



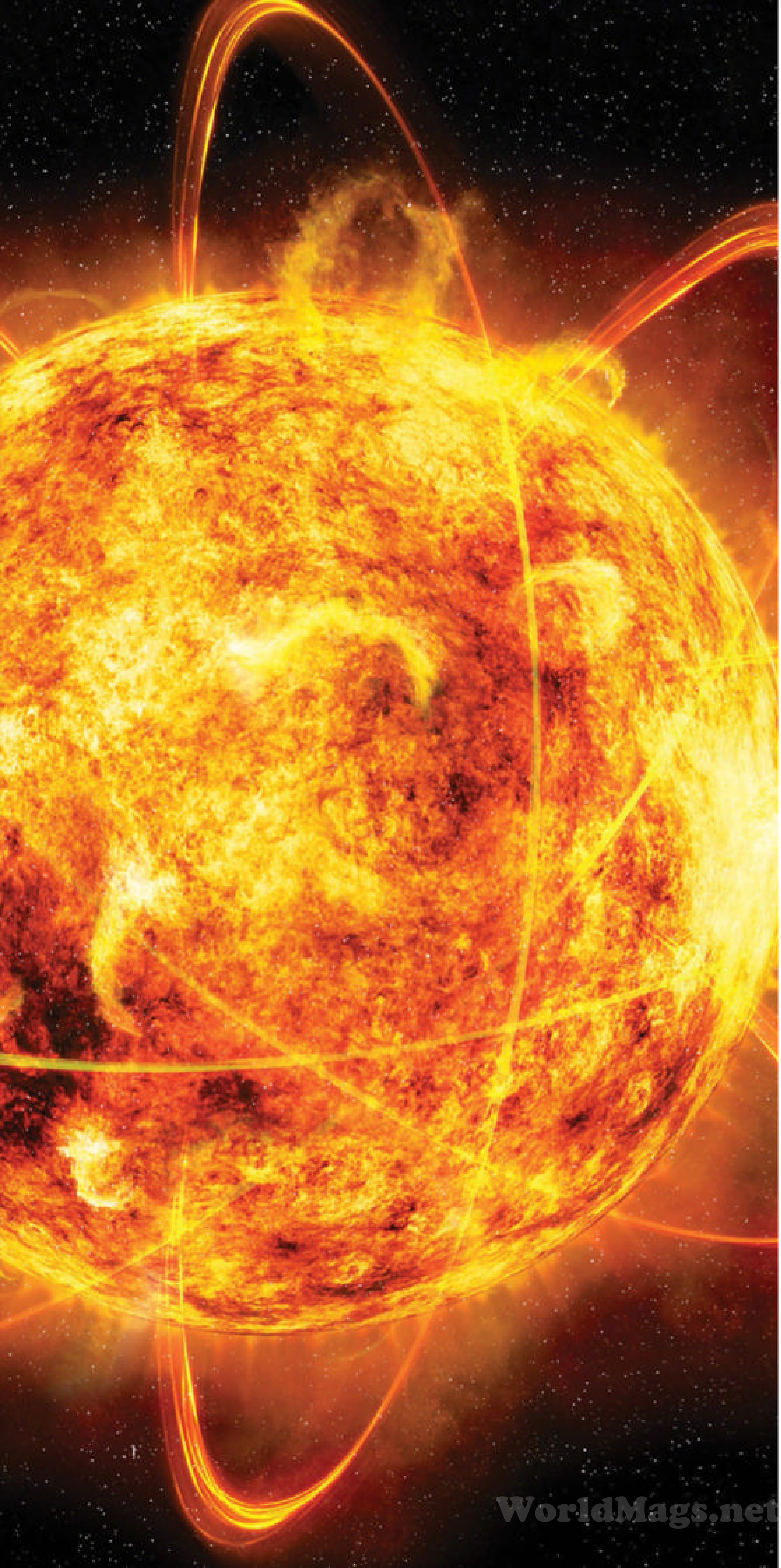
2010
NASA launches the Solar Dynamics Observatory, its primary goal being to study the influence of the Sun near Earth.



2018
NASA's new Sun-observing telescope Solar Probe Plus will launch and become the closest spacecraft to the Sun.

FUSION POWER SUN

Our local star pumps out vast amounts of heat and light, which supports all life on Earth. But where does it come from, and just what happens to it on its journey through the Sun?



Fusion power Sun

The Sun is a huge ball of blazing gas, with a visible surface roughly 1.4 million kilometres (870,000 miles) across. In a single second it pumps out energy equivalent to what could be generated by 2 billion large Earth power stations in a year, making use of a process that scientists have only been able to harness for a fraction of a second in Earth-based laboratories: nuclear fusion.

Fusion is the process of joining together the atomic nuclei of light elements to build the nuclei of heavier ones. All atoms consist of a nucleus (a tiny, positively charged core that accounts for the vast majority of their mass) surrounded by a cloud of orbiting electrons (lightweight, negatively charged particles). In comparison to the entire atom, the nucleus is about the size of a pea inside an electron cloud the size of a football stadium. In the extreme conditions of the Sun's interior, atoms break apart into their component electron and nuclei, allowing matter to reach extreme densities (about 150 times the density of water). Heated to temperatures of around 15 million degrees Celsius (27 million degrees Fahrenheit) in the core of the Sun, atomic nuclei are slammed together at high speed – and the changes they go through in order to remain stable release the energy that allows the Sun to shine.

A century ago, the source of the Sun's power was one of the biggest questions in astronomy. Geological and fossil discoveries had shown that the Earth was hundreds of millions, if not billions, of years old. But popular models of the Sun's power source, such as the idea that it generated energy by slow gravitational contraction, suggested that it could only sustain Sun-like levels of energy for a few tens of millions of years.

Clues to a solution came from a number of different directions. Spectroscopy (the analysis of light from the Sun and other objects to identify the chemical fingerprints of their constituents) had revealed that our star and most others are dominated by the two lightest and most abundant elements in the universe – hydrogen and helium. Most astronomers agreed that the Sun and planets had formed by collapsing out of a cloud of interstellar gas (mostly hydrogen) and dust similar to some of the nebulae they saw through their telescopes, and it seemed clear that stars had to become dense and hot in the first place in order to start shining. At around the same time, physicists and chemists were discovering the secrets of atomic structure for the first time, and precise measurements of atomic masses showed that a single atom of helium contained almost four times the mass of four individual hydrogen atoms.

Then, in 1920, British astrophysicist Arthur Stanley Eddington put forward an ingenious idea – what if the Sun generated its energy by combining lightweight hydrogen nuclei to make helium? If four hydrogen nuclei fuse to form a single helium nucleus, there will be a small but significant amount of mass (roughly 0.7 per cent) 'left over', and Eddington suggested this might be converted directly into a relatively large amount of energy according to Einstein's famous equation E=mc2.

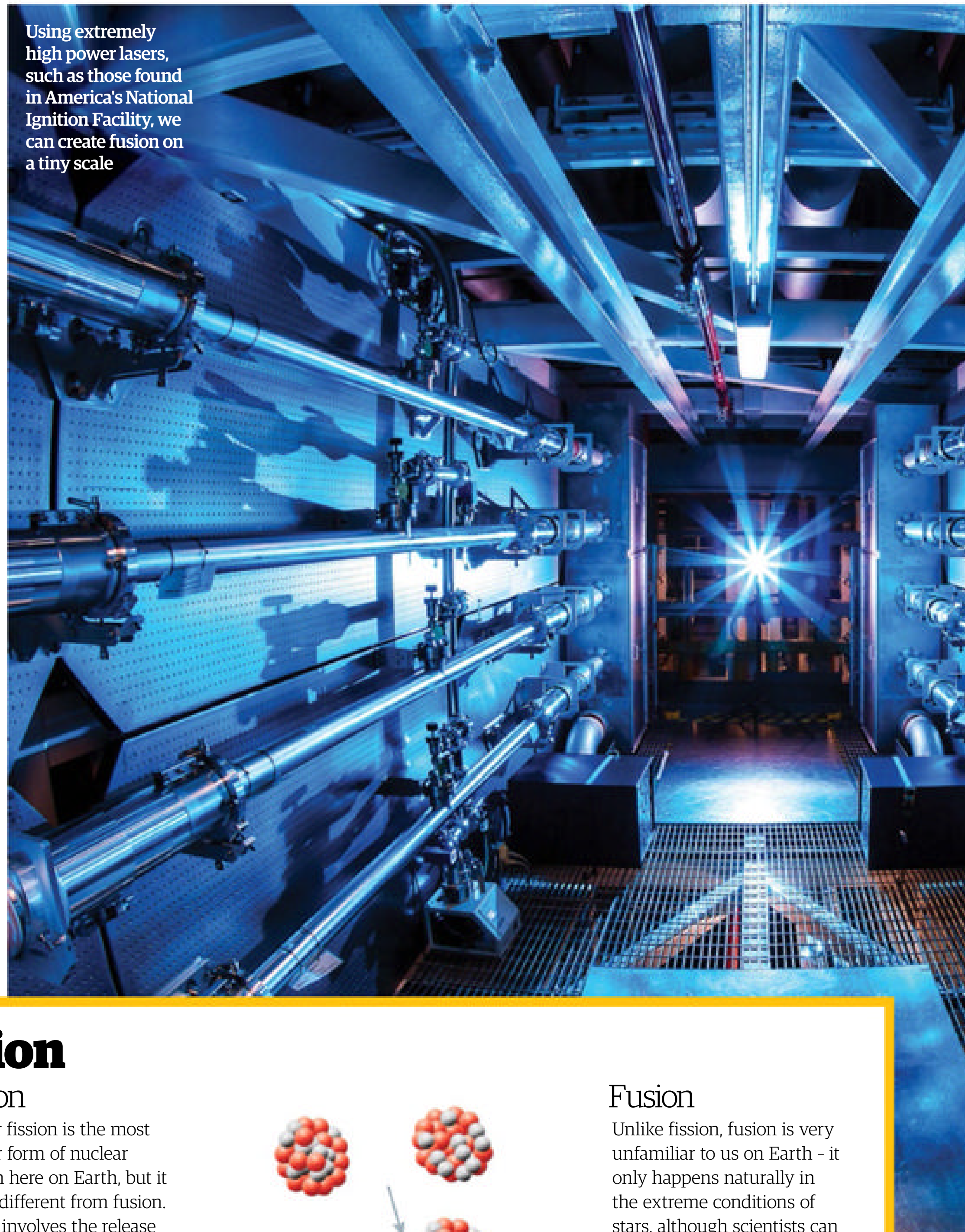
Today we know this is exactly what happens at the centre of stars like the Sun – 620 million tons of hydrogen nuclei are fused into helium every

second. However, it took decades, and many further discoveries about the nature of the nucleus, before astrophysicists could describe what happens in detail.

Nuclear fusion in the Sun takes place mostly through a process known as the proton-proton (p-p) chain. Today we know that atomic nuclei consist of two distinct particles – positively charged protons and uncharged neutrons – with identical masses. The number of protons dictates the number of electrons required to balance them, and therefore the atom's chemical properties and which element it forms. Neutrons, meanwhile, provide additional mass and stability, forming variant atoms of the same element with the same chemistry but different mass. These are known as isotopes.

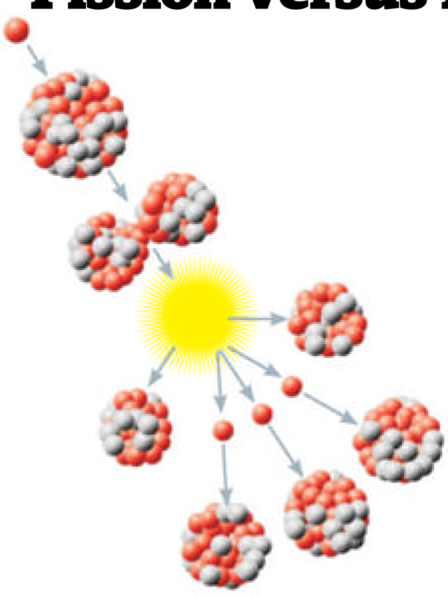
Hydrogen usually consists of atoms with just a single lone proton orbited by a single electron. In the extreme conditions of a stellar interior, however, these atoms are ionised, with their electrons stripped away to expose the bare nucleus. A helium nucleus, in contrast, contains two protons and two stabilising neutrons – so where do the neutrons come from? It seems that during the fusion process, protons are able to spontaneously transform into neutrons through a process known as beta-plus decay. The proton effectively 'sheds' its positive charge by emitting a positron (the positively charged equivalent of an electron) and an almost-massless particle known as a neutrino. P-p chain fusion actually involves several distinct pathways and each of its steps releases energy, while any positrons that may have been liberated along the way soon collide with electrons and disappear in another burst of energy known as annihilation.

At relatively large scales (those of whole atoms), we might expect repulsion due to the familiar electromagnetic force to push positively charged protons away from each other. However, given enough temperature, speed and pressure, the protons



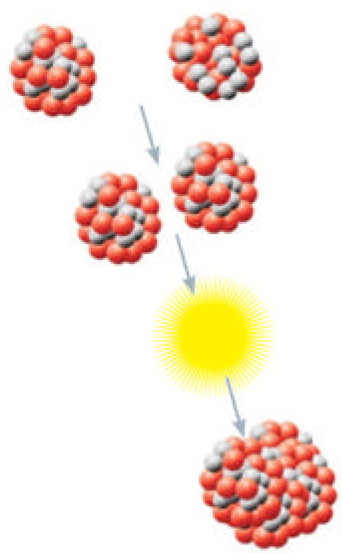
Using extremely high power lasers, such as those found in America's National Ignition Facility, we can create fusion on a tiny scale

Fission versus Fusion



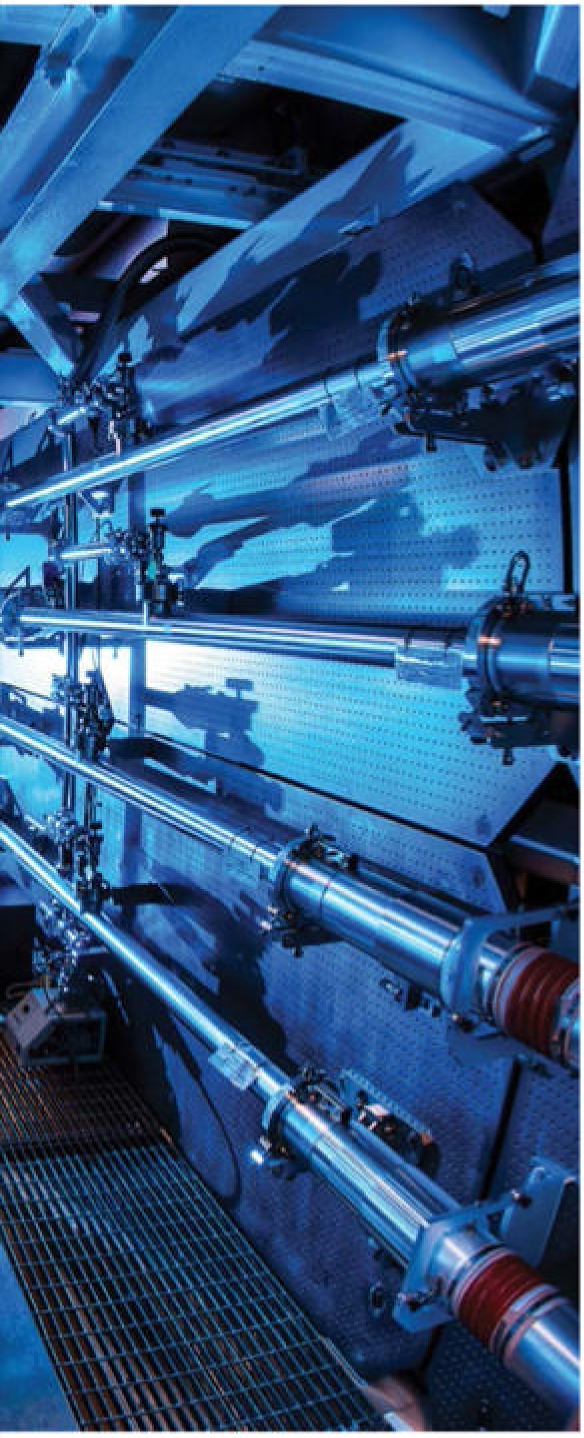
Fission

Nuclear fission is the most familiar form of nuclear reaction here on Earth, but it is very different from fusion. Fission involves the release of energy from the splitting apart of a heavy atomic nucleus whose configuration of protons and neutrons have left it unstable or 'radioactive' – it produces one or more lighter nuclei along with other subatomic particles or excess energy. Fission happens regularly in nature, but can also be triggered artificially, which is the principle behind nuclear power stations and, unfortunately, atomic bombs as well.



Fusion

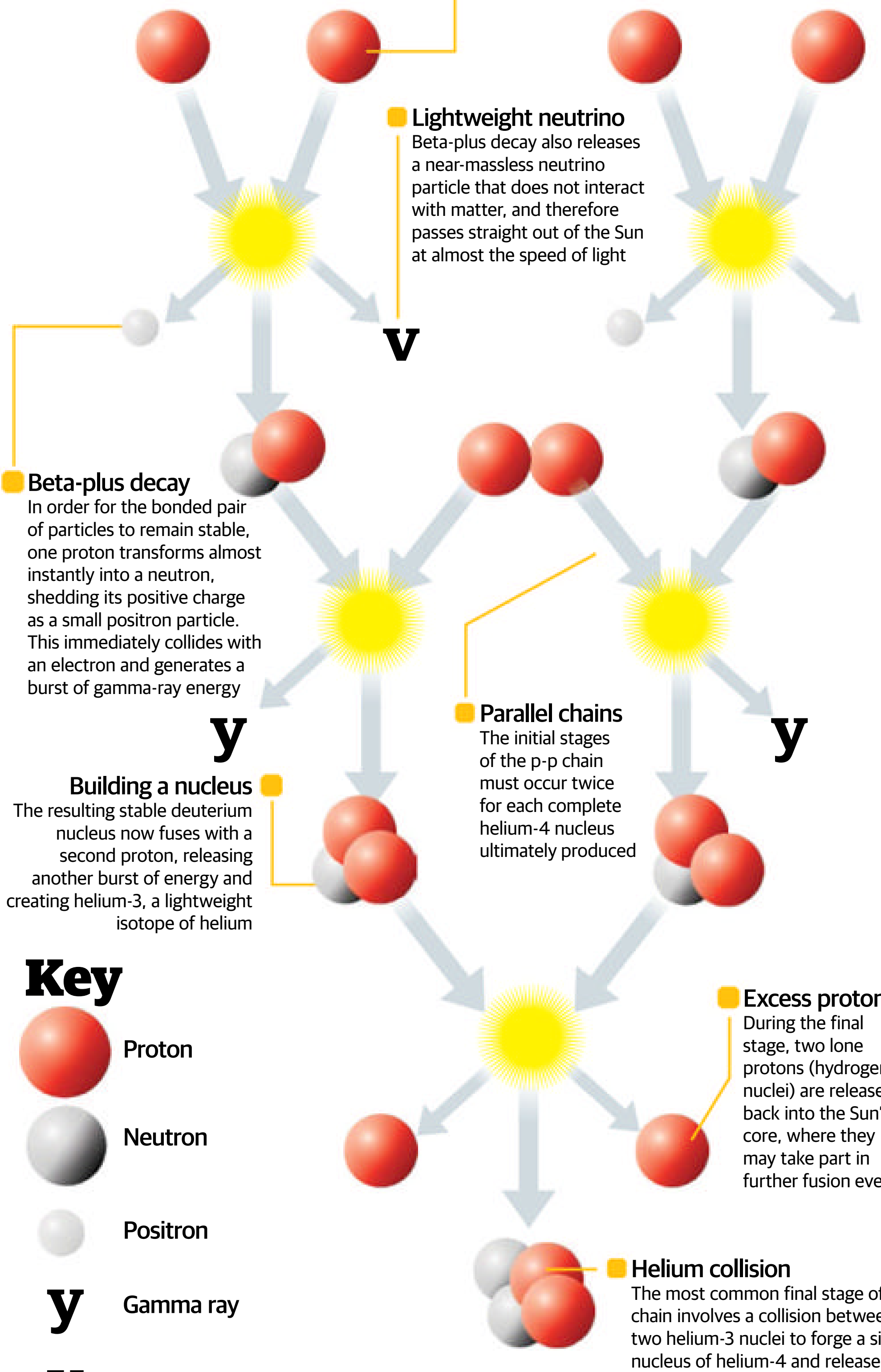
Unlike fission, fusion is very unfamiliar to us on Earth – it only happens naturally in the extreme conditions of stars, although scientists can replicate it in experiments. Fusion is the forging together of lighter atomic nuclei to make heavier ones and release energy – in the Sun, this mostly involves fusing hydrogen to make helium but in other stars it's possible to fuse elements up to and including iron (elements beyond this absorb energy in the process). Harnessing nuclear fusion remains a dream at the moment, but it offers a potentially limitless source of clean energy.



"Life on Earth could not have come into being without nuclear fusion in the Sun: we could not survive without it"

Proton-proton chain fusion

P-p chain fusion actually involves several distinct pathways, but the early steps always involve the fusing of two protons to form a highly unstable isotope called helium-2.



Colliding protons
Stripped of their electrons in the heart of the Sun, exposed hydrogen nuclei are simply individual positively charged protons. At intense temperatures and pressures, they are forced together, overcoming forces of electromagnetic repulsion

Lightweight neutrino
Beta-plus decay also releases a near-massless neutrino particle that does not interact with matter, and therefore passes straight out of the Sun at almost the speed of light

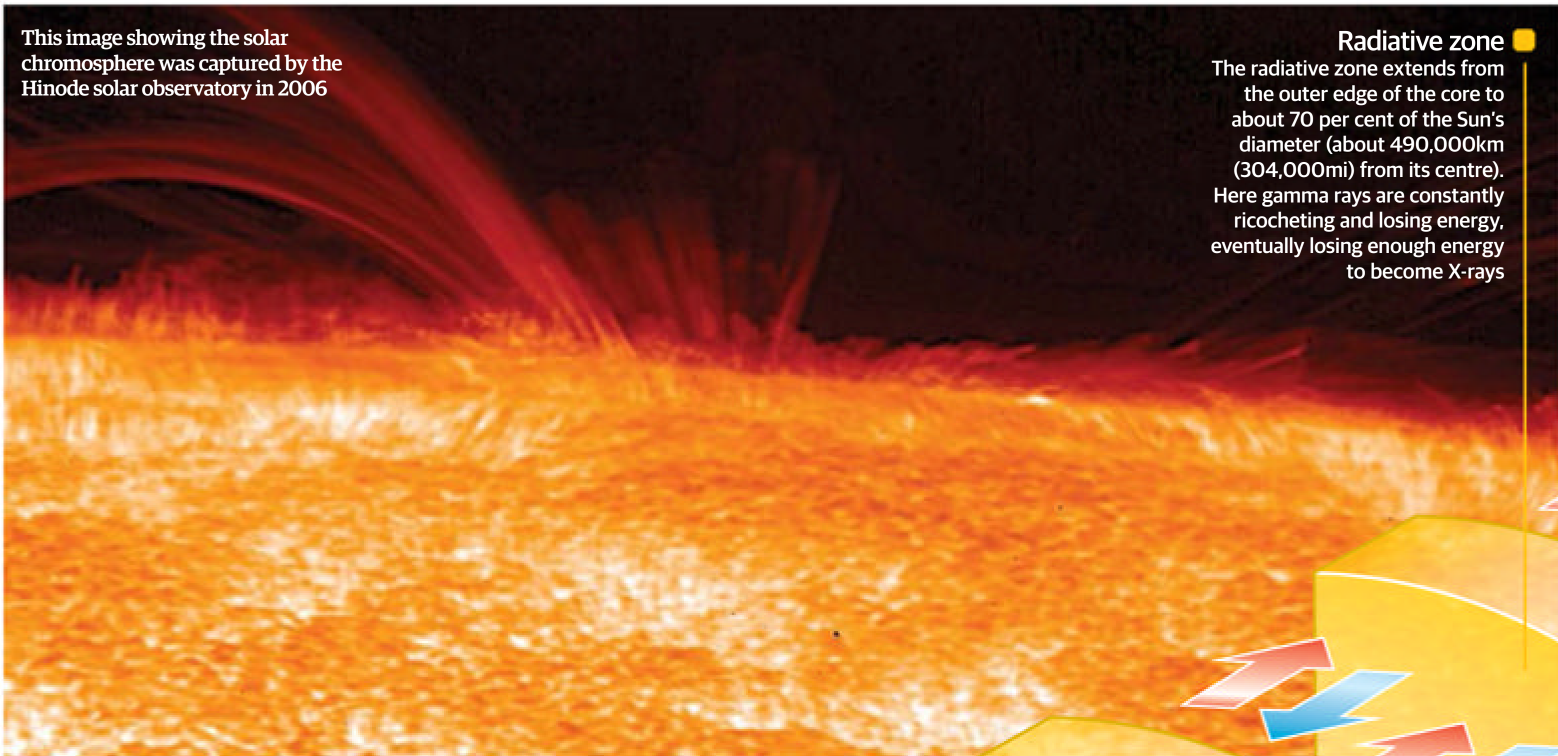
Beta-plus decay
In order for the bonded pair of particles to remain stable, one proton transforms almost instantly into a neutron, shedding its positive charge as a small positron particle. This immediately collides with an electron and generates a burst of gamma-ray energy

Building a nucleus
The resulting stable deuterium nucleus now fuses with a second proton, releasing another burst of energy and creating helium-3, a lightweight isotope of helium

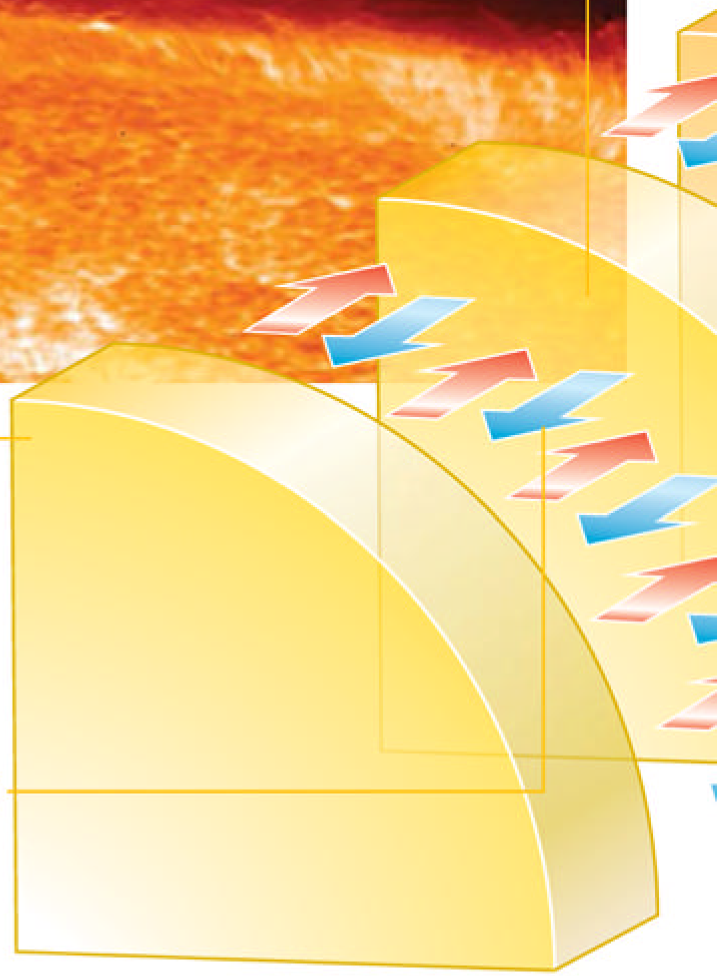
Parallel chains
The initial stages of the p-p chain must occur twice for each complete helium-4 nucleus ultimately produced

Excess protons
During the final stage, two lone protons (hydrogen nuclei) are released back into the Sun's core, where they may take part in further fusion events

Helium collision
The most common final stage of the chain involves a collision between two helium-3 nuclei to forge a single nucleus of helium-4 and release another burst of energy



This image showing the solar chromosphere was captured by the Hinode solar observatory in 2006



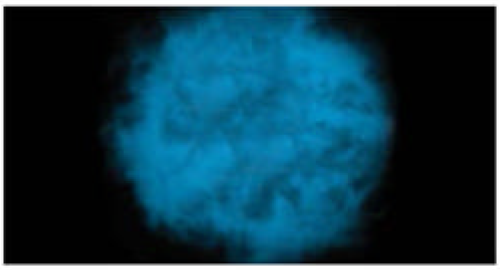
Radiative zone
The radiative zone extends from the outer edge of the core to about 70 per cent of the Sun's diameter (about 490,000km (304,000mi) from its centre). Here gamma rays are constantly ricocheting and losing energy, eventually losing enough energy to become X-rays

Inner core
The Sun's core, where fusion can be sustained, takes up about 20 per cent of its diameter (roughly 22 times the width of Earth). High temperatures and pressures allow hydrogen nuclei (protons) to fuse together, building into helium nuclei and releasing energy in the process

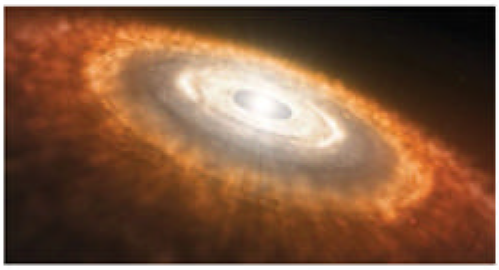
Hydrostatic equilibrium
At every point within the Sun's overall structure, the outward pressure from radiation and the inward pull of gravity must be precisely balanced to prevent material being dragged inwards or blown away

The corona is best viewed during a total solar eclipse, and shows up as a pink outline

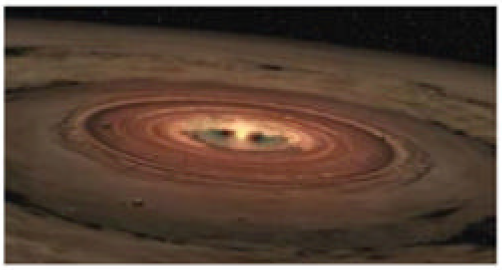
How did our Sun form?



1. Origins of a star
Our Sun and its planets were born when a hydrogen-rich cloud of interstellar gas and dust began to slowly collapse around 5 billion years ago.

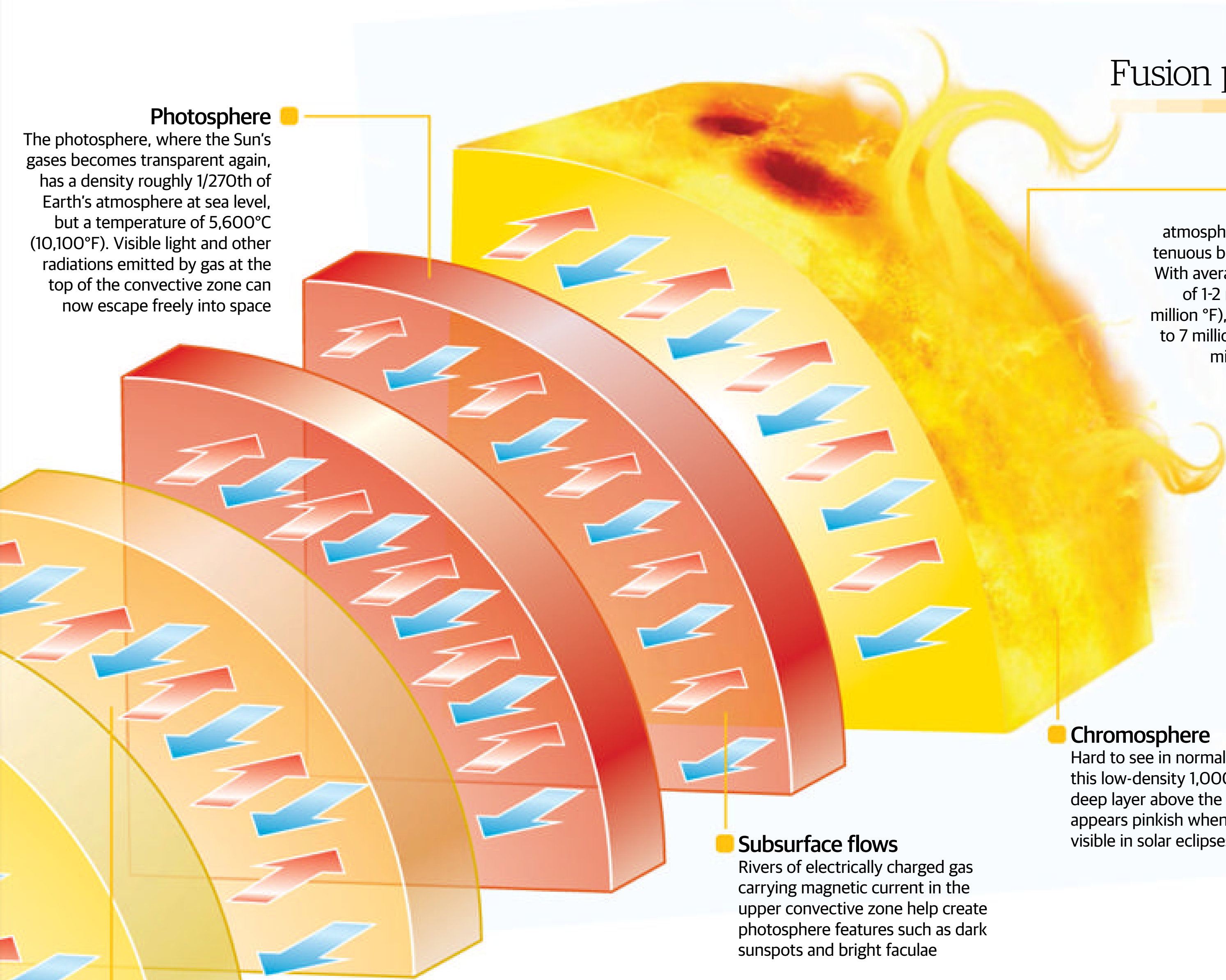


2. Flattening out
As the cloud grew denser, it span faster. Collisions within the cloud tended to even out its rotation, resulting in a flattened disc with a large central bulge.



3. Condensing Sun
As the central region of the 'protostellar nebula' grew more massive, its gravity began to pull in more material, gradually condensing and heating up.

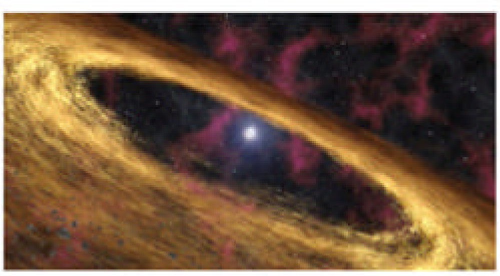
Fusion power Sun



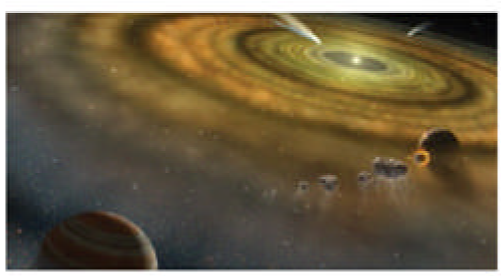
can briefly come close enough for a tremendously powerful short-range attractive force, known as the 'strong nuclear force', to overcome their electromagnetic repulsion.

As a result, the Sun can only sustain fusion in a core occupying about 20 per cent of its diameter. Power released here takes the form of gamma rays – electromagnetic waves similar to the light but with much shorter wavelengths and higher frequencies that allow them to carry much more energy. These rays still have a long journey ahead of them to reach the Sun's visible surface and escape into open space.

The Sun's interior is divided into three distinct zones – the core, the radiative zone and the convective zone. Not content with pointing to fusion as the likely source of stellar energy, it was Eddington who first theorised the existence of these zones and explained how stars as a whole remain stable, despite the firestorm raging within them. This is thanks to a balancing act called hydrostatic equilibrium: the forces acting on any arbitrary layer within the star, he showed, are always precisely balanced between outward pressure from radiation flooding away from the core, and the inward pull of gravity.



4. Protostar
At first, the Sun shone by radiating energy generated by its own gravitational contraction. It was a large, warm ball of gas surrounded by a ring of debris.



5. Ignition!
The Sun continued to grow smaller and denser, until its core became hot enough to begin nuclear fusion. Meanwhile the debris around it formed into planets.

6. The Solar System today
The Sun is roughly halfway through an estimated 10 billion year lifetime during which it will continue to shine by fusing hydrogen into helium in its core.

As its name suggests, the radiative zone is the region where energy is transferred mainly through radiation (the same is true of the core itself). The sea of particles is so tightly packed that gamma rays can travel for only a very short distance before interacting with something (usually a fast-moving 'free electron'). Each interaction 'scatters' the gamma ray, transferring a little of its energy to the particle and therefore helping to retain the heat of the central regions. Each scattering event sends the gamma ray off in a new direction, and as the gamma rays ricochet from one particle to the next, they follow a long and complicated path known as a 'random walk'.

It might seem as though the gamma rays would be perpetually trapped in the central region, but the very gradual fall-off in density of material from the centre of the Sun outwards ensures that rays are more likely to travel slightly longer distances before scattering, if they move in directions that are away from the centre. Therefore, over countless interactions, the gamma rays gradually lose energy and move into the Sun's less dense upper layers.

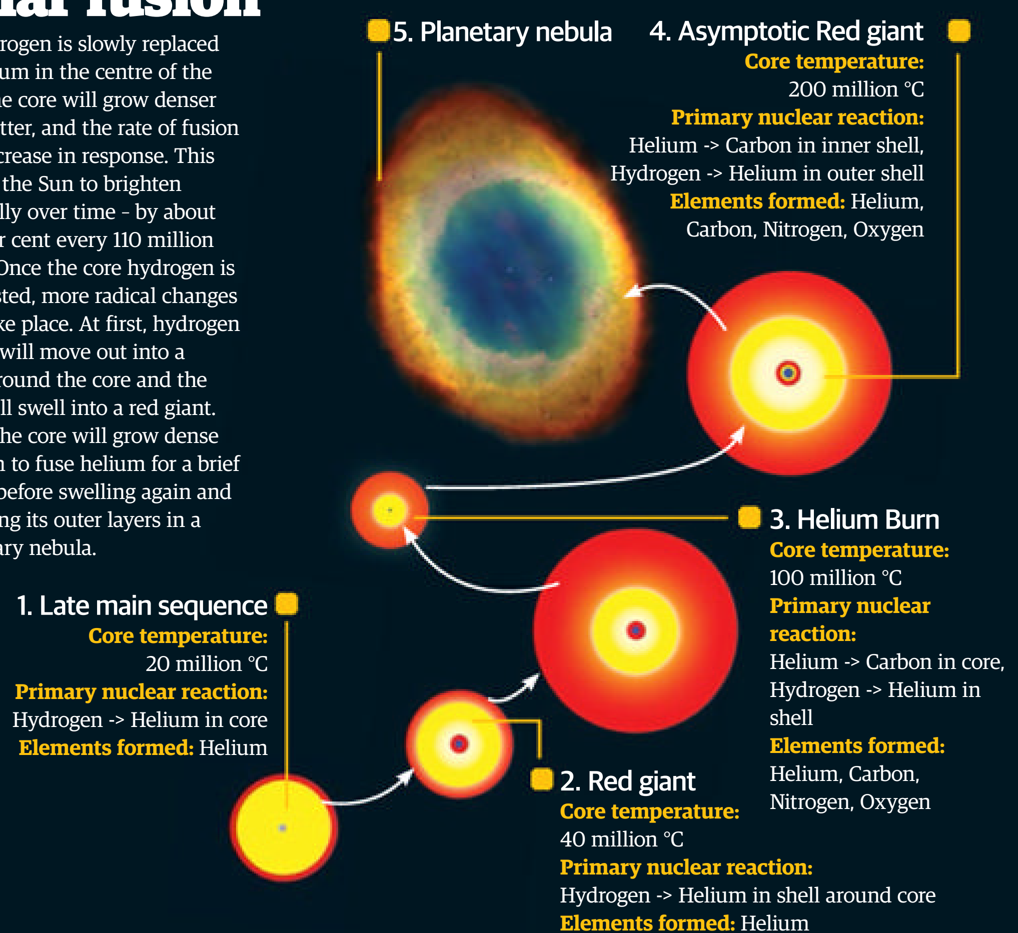
According to the latest models, radiation takes about 170,000 years to travel through the core and radiative zones, moving at an average speed of just 2.9 kilometres (1.8 miles) per year. By the time they reach the upper edge of the radiative zone, 70 per cent of the way to the Sun's surface, the surrounding temperatures have dropped to about 1.5 million degrees Celsius (2.7 million degrees Fahrenheit) and the wavelength of the rays has lengthened considerably – they are now mostly X-rays rather than gamma rays.

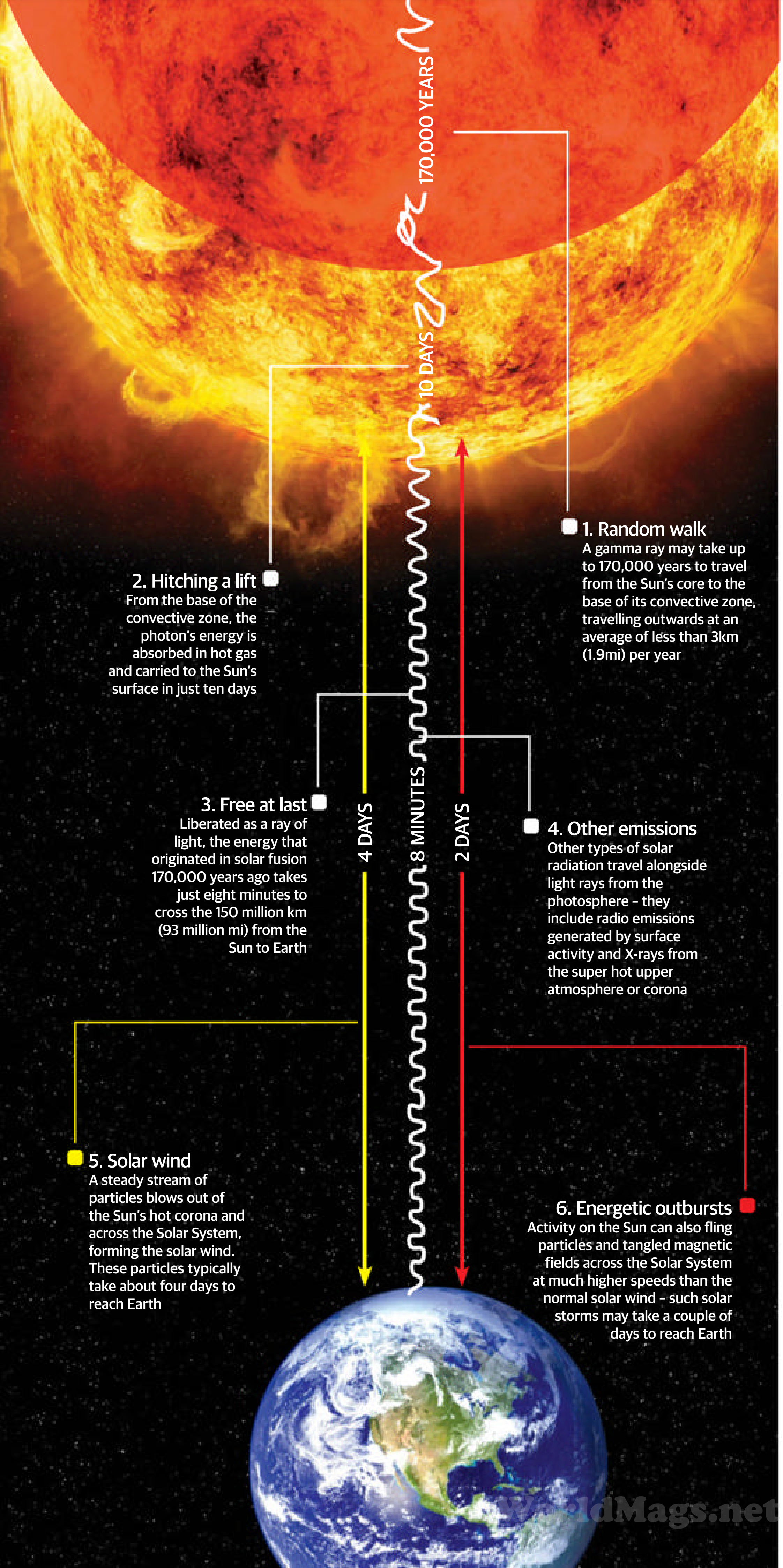
Here, at the bottom of the Sun's convective zone, conditions change rapidly from those below. The Sun's materials become more opaque, but also develop a greater ability to absorb heat energy, so radiation ceases to be the most efficient means of transferring energy outwards. Instead, convection (the bulk movement of heated matter) takes over. X-rays heat gas at the bottom of a layer more than 200,000 kilometres (124,000 miles) deep, and as this gas heats and expands, it rises up through overlying cooler gas, taking about ten days to complete the final leg of its journey towards the Sun's surface.

Almost 700,000 kilometres (435,000 miles) from its centre, the Sun's composition changes dramatically once again. As temperatures drop to around 5,600 degrees Celsius (10,100 degrees Fahrenheit), light-absorbing ions that are common in the convective zone disappear, leaving most of the gas in a pure atomic form that is transparent to visible light. Radiation once again becomes the most efficient means for energy to escape, and so electromagnetic rays emitted by the searing gas are no longer reabsorbed and can escape into space.

The future for solar fusion

As hydrogen is slowly replaced by helium in the centre of the Sun, the core will grow denser and hotter, and the rate of fusion will increase in response. This causes the Sun to brighten gradually over time – by about one per cent every 110 million years. Once the core hydrogen is exhausted, more radical changes will take place. At first, hydrogen fusion will move out into a shell around the core and the Sun will swell into a red giant. Later, the core will grow dense enough to fuse helium for a brief phase before swelling again and shedding its outer layers in a planetary nebula.





This transition region between the opaque inner Sun and its transparent upper atmosphere can be a few hundred kilometres deep and, if viewed close up, would resemble the gradual clearing of an incandescent fog. However, on the scale of the Sun as a whole, the boundary is very thin, and so the Sun appears to have a sharply defined outer surface called the photosphere.

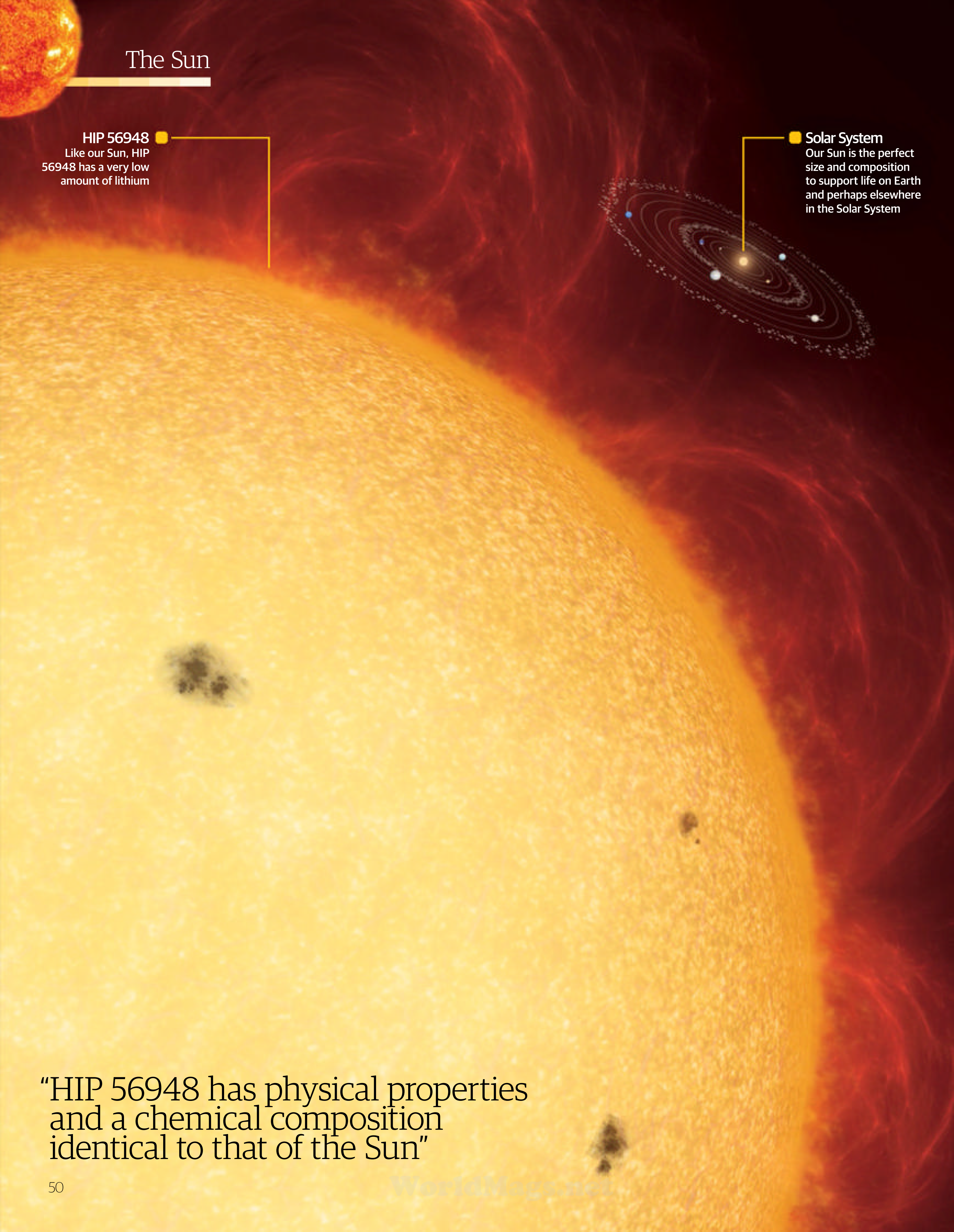
Thanks to the relatively low temperature of the Sun's surface, it releases a mixture of different radiations – ultraviolet rays, visible light and infrared (heat) radiation. These might be comparatively feeble compared to the original gamma rays generated in the core, but the energy they have lost along the way has helped to sustain the Sun's internal power plant.

The Sun's surface and upper atmosphere are the only parts of our star that we can observe directly, but they reveal a great deal about the processes going on within. Viewed through a filter that blocks out most of its blazing light, the photosphere is alive with a seething, shifting pattern of bright, dark-edged spots known as granulation. Each granule marks a single convection cell – the bright spot is formed where rising hot gas radiates its energy away into space, while the dark rim is formed of cooling gas sinking back down towards the interior. Individual granules are a relatively short-lived phenomenon of the upper convection zone – perhaps 1,500 kilometres (932 miles) across and with lifespans of just 15 minutes. However they're supported on deeper and larger 'supergranules', up to 30,000 kilometres (18,000 miles) wide and with lifespans of up to a day.

In addition to these fairly placid, ongoing processes, the photosphere (together with a thin overlying layer called the chromosphere) also develops a variety of more dramatic, intermittent features such as dark sunspots, bright faculae and looping arcs of gas known as prominences. Such features are linked to changes to a solar magnetic field generated within the churning convective zone. These come and go with the waxing and waning of the 11-year solar cycle and are linked to more violent events such as solar flares.

According to most calculations, nuclear fusion should supply enough energy to keep the Sun shining for about 10 billion years before the supplies of fuel in its core are exhausted. So given that the Solar System formed some 4.5 billion years ago, we're about halfway through the Sun's hydrogen-burning lifetime. As the hydrogen starts to run out, physical changes to the structure of our local star will enable it to keep shining for perhaps 2 billion years more, but they will have a profound influence on the entire Solar System and certainly leave Earth uninhabitable long before then.

Today, however, our planet basks in the energy generated by a nuclear furnace 150 million kilometres (93 million miles) away. Happily for us, the radiation the Sun releases at its surface is a lot less damaging to living tissues than that generated in its core – thanks in large part to about 500,000 kilometres (310,000 miles) of shielding in the form of the radiative and convective zones. Life on Earth could not have come into being without nuclear fusion in the Sun, we could not survive without it – and perhaps one day we will even learn to harness it for our own purposes.



"HIP 56948 has physical properties and a chemical composition identical to that of the Sun"

The Sun's twin star

The most Sun-like star that we know of could kick-start the search for extraterrestrial life in the universe

Since the dawn of mankind our Sun has been regarded as unique. In ancient times it was thought to be the only star in existence, responsible for determining the day and night cycles on Earth. In the modern era we know it to be the heart and soul of the Solar System but it has long been regarded as one-of-a-kind in its composition and size. Now, however, it appears that our Sun could just be one of many similar stars in the Milky Way alone, providing a key piece of evidence to the belief that life could be lurking elsewhere in the universe.

The Sun is about 4.6 billion years old, born from a cloud of hot dust and gas at the start of the Solar System. In that time it has dictated the motion and characteristics of every body in its vicinity, including providing our own Earth with the ability to support life. As astronomers began to discover and study more and more stars elsewhere in the universe, they noticed several key differences between the Sun and every other star that seemed to make our own just that little bit special.

First, every star they came across was either much larger or significantly smaller. Second was that most other stars were considerably older or younger. Third, and perhaps most important, was the puzzling discovery that our Sun contained a very low amount of lithium compared to other stars. If all stars were essentially created in the same manner, why did this level of lithium vary so much?

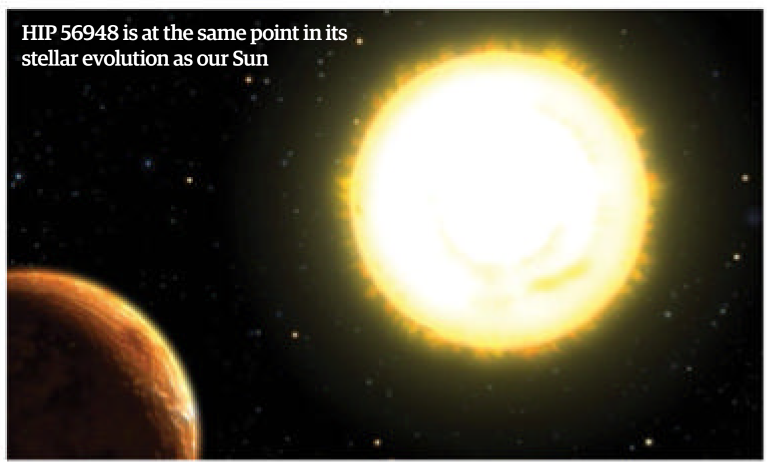
A reason for this was theorised in 2009 in a paper published in Nature. "The explanation of this puzzle is for us rather simple," said lead author and astrophysicist Garik Israelian. "The Sun lacks lithium because it has planets." Rather than close the case, however, Garik's proposal carried with it a much more pertinent question. If we could find a solar twin with a similar lithium content, would that be indicative of that star also having a similar planetary system to our own?

Astronomers began to search in earnest for such a solar twin, but to little avail. That was until a paper published in 2012 proclaimed to have not only found a star similar in size and age to our Sun, but also nearly identical in its composition. HIP 56948 is about 210 light years away in the Draco constellation. It has a radius 1.14 times that of our Sun, a mass slightly smaller and is almost identical in age, meaning it is at the same point in its stellar evolution. In the paper, entitled 'HIP 56948: A Solar Twin with a Low Lithium Abundance', authors Jorge Meléndez and Iván Ramírez said: "HIP 56948 has stellar parameters identical to solar within the observational uncertainties, being thus the best solar twin known to date. Considering the age of this star and its location and orbit around the galaxy, if terrestrial planets exist around it, they may have had enough time to develop life."

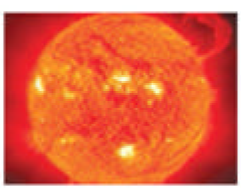
Of most interest, however, was the revelation that HIP 56948 shared similar levels of lithium depletion as our own Sun, pointing to the presence of planets. However, there are no signs of large and hot Jupiter-like gas giant planets, suggesting that much smaller (and perhaps terrestrial) planets are in orbit. Finding such a star was a remarkable achievement, for our own Sun is regarded as one that has the optimal conditions around which such potentially habitable planets can form. Thus, in our continued search for life outside the Solar System, HIP 56948 represented a significant step forwards in the hunt for life-bearing exoplanets.

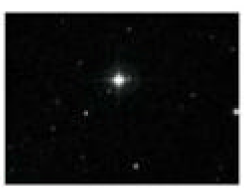
"HIP 56948 has physical properties and a chemical composition identical to that of the Sun, as well as a similar age," the paper continued. "Stellar ages are key in the search for complex life, especially if one considers that the formation timescale of complex life is similar to that for Earth. Furthermore, given its orbital properties, HIP 56948 is well within the galactic habitable zone. Considering these facts, HIP 56948 is an excellent candidate for life outside the Solar System."

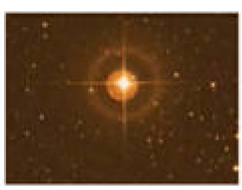
In fact, the star is so Sun-like that Meléndez and Ramírez suggest it may completely change our understanding of how unique we are in the universe. "Besides the astrophysical significance of solar twins, there is another motivation to study them in detail: they help in answering the question of whether the Sun is unique or not, a question that has important philosophical consequences." Those consequences would be that there might be other places in the Milky Way, and the universe, where life such as ourselves could flourish. If the Sun were unique it would "suggest that our location in the universe is privileged for our existence as observers." The identification of HIP 56948, however, "can be used as an argument against [that theory]," and therefore allow us to theorise that there are many stars like our own Sun that have the necessary conditions around which life can form. Perhaps HIP 56948, our closest solar twin and a star not that far away in terms of astronomical distance, might just be one of those stars.

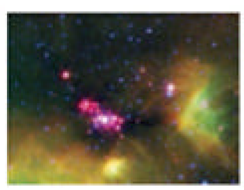

HIP 56948 is at the same point in its stellar evolution as our Sun

The universe's Sun-like stars
Our Sun and its potential solar twins

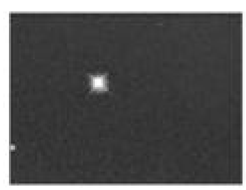

The Sun
Radius: 696,000km
Distance: 150 million km
Surface temp: 5,778 K
Age: 4.57 billion years


HIP 56948
Radius: 1.14 Suns
Distance: 210 light years
Surface temp: 5,748 K
Age: 3.6 billion years


18 Scorpii
Radius: 1.01 Suns
Distance: 45.3 light years
Surface temp: 5,433 K
Age: 4.7 billion years


HD 143436
Radius: Unknown
Distance: 142 light years
Surface temp: 5,768 K
Age: 3.8 billion years

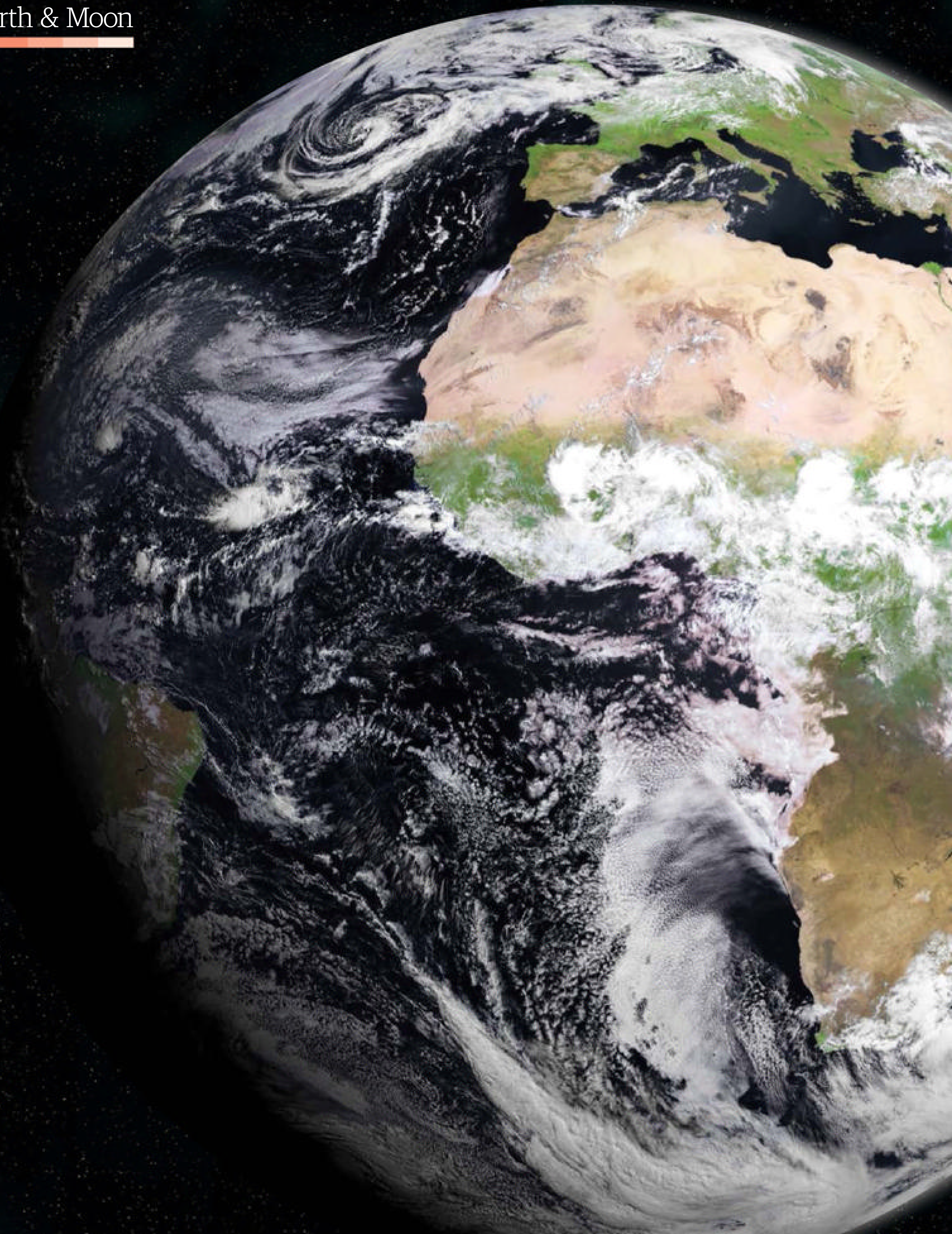

HD 44594
Radius: 1.0 Suns
Distance: 82 light years
Surface temp: 5,840 K
Age: 4.1 billion years


HD 98618
Radius: 1.0 Suns
Distance: 126 light years
Surface temp: 5,843 K
Age: 4.21 billion years

The Earth & Moon

Understand more about our home planet and its only satellite

> "The Moon is in synchronous rotation with the Earth – its rotation and orbital period are the same – so the same side is always facing Earth"



All About... EARTH

When it comes to studying the planets of the Solar System we often overlook the Earth. However, as the only planet known to be able to support life, there's still lots to learn about our fascinating home planet

Like the TV show says, the Earth is indeed the third 'rock' from the Sun – it's also the largest of our Solar System's four terrestrial planets, the fifth-largest planet and the densest planet overall. It's called an oblate spheroid – it's flattened at the poles, but bulgy at the equator, thanks to forces from the Earth's rotation. The bulge means that the furthest point from the centre of the Earth to the surface is located in Ecuador. The Earth has a density of 5.52 grams per cubic centimetre, a mass of 5.98 x 10^{24} kilograms and a circumference of 40,075 kilometres (25,000 miles).

Earth rotates on its axis once approximately every 24 hours, although the length of a true solar day (measured from noon to noon) always varies slightly due to small changes and eccentricities in the planet's rotation and orbit. Speaking of orbit, Earth has an eccentric, elliptical one. It completes an orbit around the Sun once every 365.26 days, at a mean distance of 150 million kilometres (93 million miles). The axial tilt of 23.4 degrees means that the northern and southern hemispheres are exposed to the Sun at different times, resulting in our four seasons.

The Earth is not the only planet to have a moon, but the relationship that we have with ours has had a measurable effect on everything from our climate to the length of our year. The Moon is tidally locked to the Earth – it has a rotational period that's the same length as it takes to orbit our planet. This means that the same side is always facing us. Tidal interaction means that the Moon is moving away from us at a rate of about 38 millimetres (1.5 inches) per year. The tides aren't just caused by the gravitational pull of the Moon, though; it's a complex relationship between the Moon, the Sun's gravity, and Earth's rotation. Not only do the tides cause sea levels to rise and fall, but they may also be what's keeping the Earth's tilt stable. Without it, some scientists believe, the tilt may be unstable and result in chaotic changes over millions of years.

Just as the Sun and Moon affect the Earth, our planet also has a noticeable effect on objects around it. Since the Moon's formation, the Earth has acted like a bit of a cosmic bully, pushing and pulling it until it fell into line. There are other objects that Earth has an effect on as well. Asteroids, comets and spacecraft have all been hindered or helped by the Earth's gravity in their motion, unable to avoid the inevitable influence when they come into its vicinity.

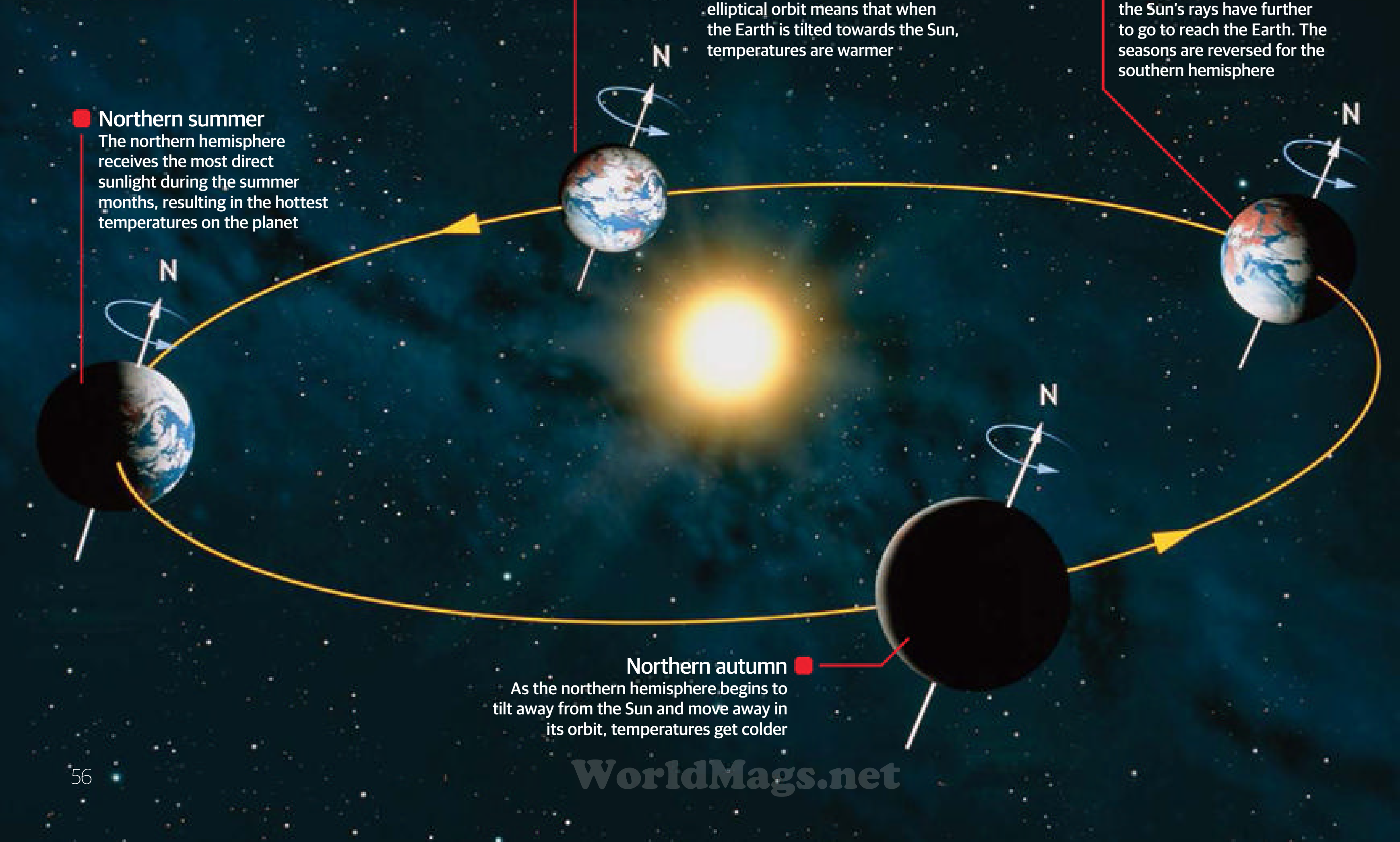
An object falling freely near Earth's surface will experience an acceleration of about 9.81 metres (32.2 feet) per second every second, regardless of its size. Owing to the bulge mentioned earlier, this gravitational force is slightly different across the Earth. At the equator a falling object accelerates at about 9.78 metres (32.09 feet) per second every second, while at the poles it is closer to 9.83 metres (32.35 feet).

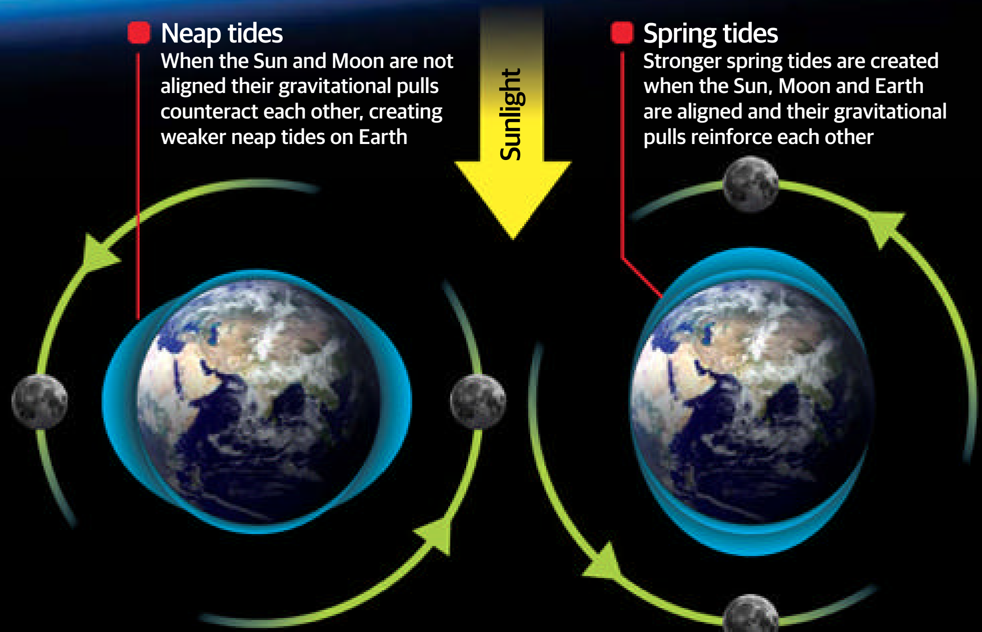
As you move away from Earth's surface the gravitational force decreases but at a barely noticeable rate. If you stood atop Mount Everest, at 8,848 metres (29,029 feet) tall, you'd weigh about 0.28 per cent less. Even at an altitude of 400 kilometres (250 miles), the gravitational force you'd feel is still 90 per cent as strong as it is on Earth's surface; the feeling of weightlessness in orbit is instead due to your horizontal velocity, which is so fast that you continually fall towards Earth.

Beyond Earth, our planet's gravitational pull continues to decrease, but in smaller increments. Even at a height of 2,000 kilometres (1,240 miles) you'd still experience a pull of just under six metres (20 feet) per second every second.

> "Tidal interaction means that the Moon is moving away from us at a rate of about 38 millimetres per year"

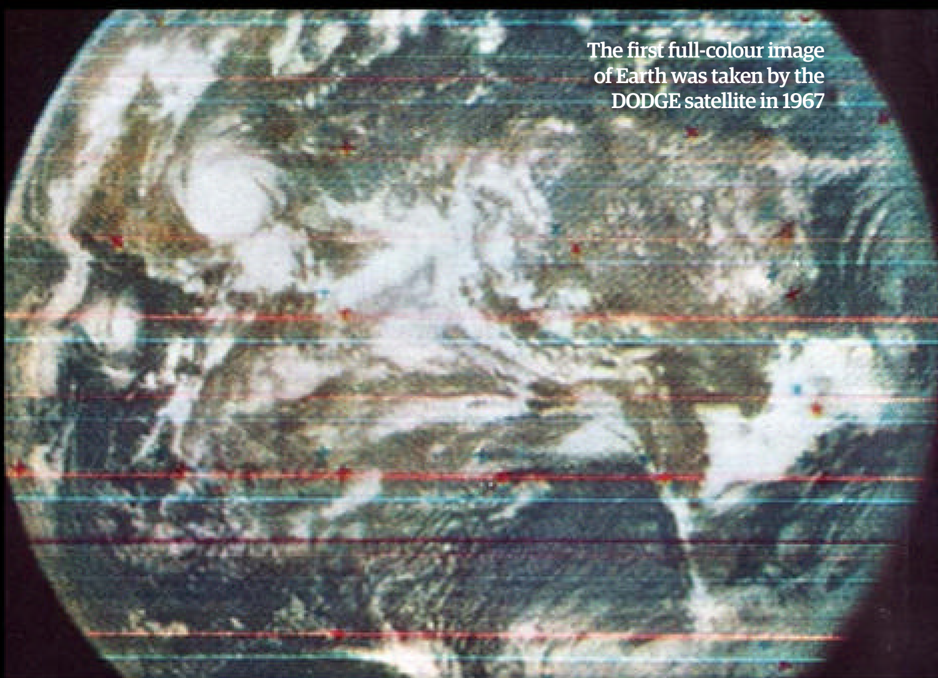
Orbits and seasons





Earth's tides

The alignments of the Sun and Moon affect the tides. The Sun's large mass means that the tidal forces it exerts on the Earth are half those of the Moon despite its distance from the Earth. At the first and third quarter Moons (above left), the Sun and Moon are in opposition and produce neap tides, which are lower amplitude. Higher-amplitude spring tides are produced during times of new Moon and full Moon.



The first full-colour image of Earth was taken by the DODGE satellite in 1967

The Earth in numbers

Fantastic figures and surprising statistics about Earth

3,000

There are around 3,000 operational satellites and 8,000 man-made objects (including decommissioned satellites) in Earth orbit

17 days

It would take about 17 days at 100km/h (62mph) to drive around the Earth

360°

It looks like a perfect sphere, but the Earth bulges at the equator and is flattened at the poles

2 As well as the Moon, the Earth has two co-orbital satellites. They're the asteroids 2002 AA29 and 3753 Cruithne

10cm The islands of Hawaii move about 10cm towards Japan each year

5 billion

The Sun will expand and become a red giant in about five billion years – likely engulfing all of the inner planets, including Earth

The planets in relation to the Sun

Earth lies 150 million km (93 million mi) from the Sun on average, known as 1 astronomical unit

All figures = million miles from Sun

Earth inside and out

How Earth formed into the habitable world we know today

You may think you know all there is to know about Earth, but we take the wonders of our home planet for granted sometimes. It's unique because it's the only planet that has all of the elements needed to support life. It's also incredibly diverse, from the vast array of geographic features to the millions of plant and animal species. If you want to explore the unknown, there's no need to look to the stars; we're always discovering something new about our own planet.

But let's start with the basics. Along with the other planets, the Earth formed from the solar nebula – a cloud of dust and gas left over from the Sun's formation – about 4.54 billion years ago. It may have taken between 10 and 20 million years for the Earth to fully form. It started out as a molten planet, but a buildup of water in the atmosphere cooled the outer layers, forming a solid crust.

The minerals found in the Earth are too numerous to mention, but just eight of them make up about 99 per cent of the entire Earth: iron, oxygen, silicon, magnesium, sulphur, nickel, calcium and aluminium.

From the inside out, the Earth comprises a core, mantle, crust and atmosphere. While the other terrestrial planets are also mostly divided this way, Earth is different because it has both an inner and outer core. The inner core is solid, while the outer core is liquid, and both contain mostly iron and nickel. The Earth's core is 6,700 degrees Celsius (12,100 degrees Fahrenheit) at the centre. This heat has two sources. The major source is radioactive decay, while about 20 per cent comes from energy generated by the gravitational binding of the planet. At formation, the Earth's core was even hotter – it has cooled as some of the radioactive isotopes have depleted.

Enclosing the core is the mantle, which is divided into two layers – a highly viscous liquid, topped by a rigid rocky layer. Finally, there's the crust – a thin rocky layer separate from the mantle because the mineral make-up is different.

Of course, these are the layers of the Earth as we know them today – numerous processes over our planet's life span have influenced and changed its make-up. The Moon is one example. It formed not long after the Earth. There have been several theories as to how this happened, but the prevailing belief is that a large object about the size of Mars collided with the Earth. Some of the object's mass merged with the Earth, some shot out into space and some formed into the Moon.

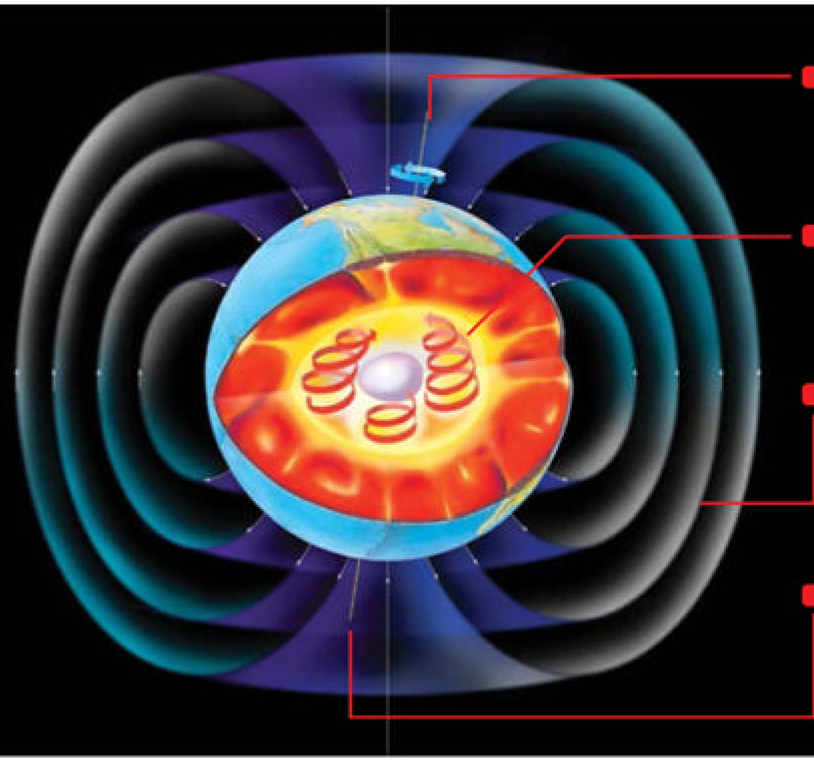
Asteroids, comets and other objects passing by deposited water and ice, ultimately leading to the formation of the oceans. The Sun was still forming at this time, too, and as its activity increased, so did the Earth's temperature. Volcanic activity and outgassing are responsible for the Earth's initial atmosphere. This multilayered atmosphere includes 78 per cent nitrogen, 21 per cent oxygen, and trace amounts of other elements. The layer of ozone blocks ultraviolet radiation from the Sun, protecting life below. Ozone is also part of the greenhouse effect, which helps sustain life on Earth. Gases trap heat rising from the surface, which keeps the average temperature at 15 degrees Celsius (59 degrees Fahrenheit).

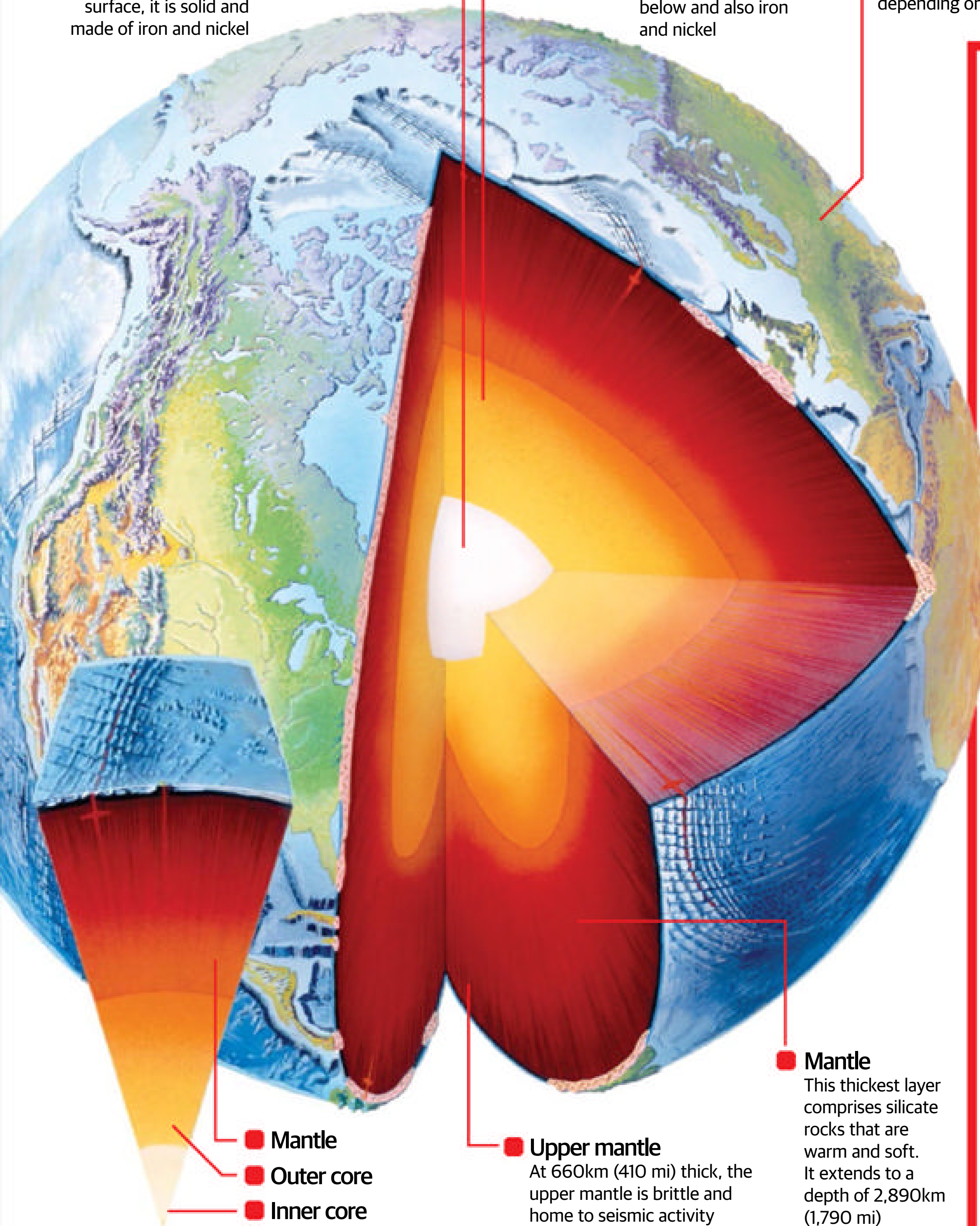
Beyond the thinnest, uppermost layer of the atmosphere, the troposphere, lies the magnetic field. It protected the gases in the atmosphere from being sheared away and carried off into space by the solar wind. The field surrounds the Earth and has poles that roughly correspond to the Earth's magnetic poles.

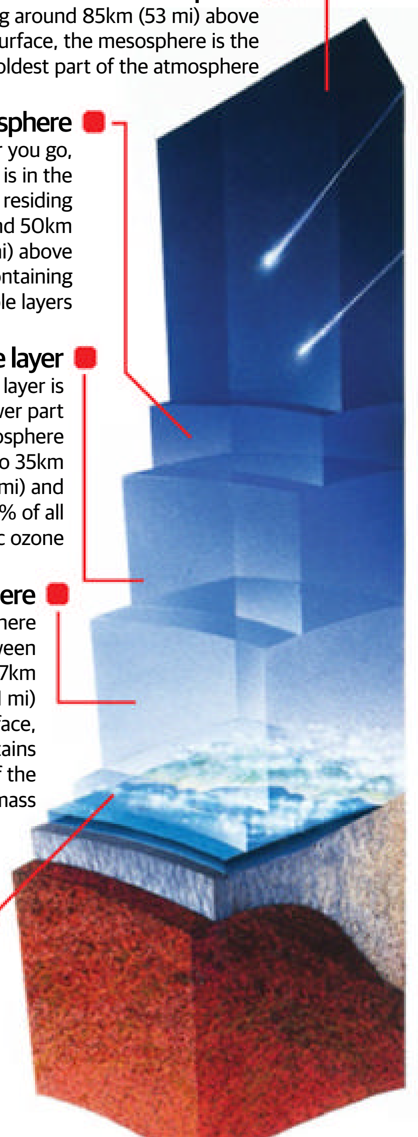
"The Earth formed from the solar nebula – a cloud of dust and gas left over from the Sun's formation"

Earth's magnetic field

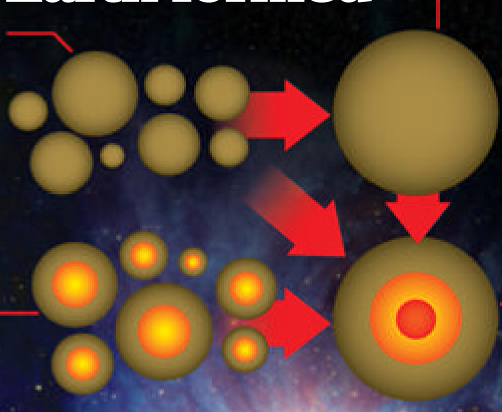
The Earth's magnetic field is generated from its molten outer core, known as a dynamo. It's created when the liquid iron within rotates, convects and generates electricity. The field extends about 63,700km (39,500 miles) from the Earth on its Sun side and 384,000km (238,600 miles) on the Moon side. It's as if there's a bar magnet at the centre of the Earth, with northern polarity corresponding with the South Geographic Pole and vice versa, but in the Earth's case, the 'magnet' is tilted at about 11 degrees. Every several hundred thousand years, the magnetic poles swap with each other. Magnetic lines extend from each pole and loop around to each other, with the lines spreading further apart as they move out from the centre. The solar wind also distorts the lines, and the field moves over time with shifts in the dynamo.







How the Earth formed



Earth's atmosphere

Earth is the only planet in the Solar System with an atmosphere that supports life. It was oxygen-rich initially thanks to the prevalence of water in the form of gas, ice and liquid, which came from its formation and other astral bodies. Some of the gases were released by activity on Earth while it was forming, and others came from organisms living on our planet. Carbon dioxide, for example, is necessary for plant growth. The plants in turn release oxygen. Carbon dioxide also helps to keep the planet warm enough to sustain life. The ozone layer traps in heat, too. But without the pull of gravity and the magnetic field, Earth would've lost its atmosphere long ago.

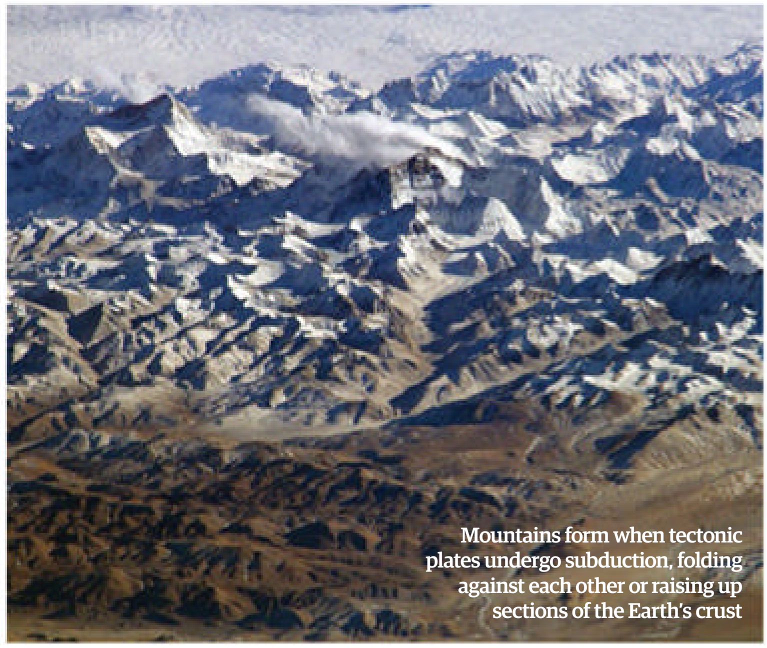
On the surface

Our planet is changing all the time, all the way down to its mantle

While we typically divide the Earth into crust, mantle and core, there are other ways of differentiating the outer layers. The lithosphere comprises both the crust and part of the upper mantle – specifically, the part that is rigid but has elasticity and becomes brittle over thousands of years. Underneath is the asthenosphere, a deeper part of the mantle that behaves like a viscous fluid. The lithosphere is divided into tectonic plates, pieces that are about 100 kilometres (62 miles) thick and move on top of the flowing asthenosphere. There are seven major plates: African, Antarctic, Eurasian, Indo-Australian, North American, Pacific and South American. These include the continents and the Pacific Ocean, while smaller plates make up the rest of the Earth. They can comprise continental crust (which is mostly granitic rock), oceanic crust (mostly mafic rock), or some of both. Continental crust is thicker but not as dense as oceanic crust.

Plate movements occur at the boundaries between them. At convergent boundaries, plates can move under each other (or subduct) or collide in the case of continental crust. At divergent boundaries, the plates slide away from each other. Plates grind along each other at transform boundaries. Volcanoes and earthquakes often occur along boundaries between plates. Plate boundary movement is also responsible for creating oceanic trenches and mountains. Some plates have hot spots – areas of volcanic activity under the mantle within the plate, where volcanoes often form. While material can be lost through subduction, more is formed along divergent boundaries in a process known as sea floor spreading. That's why some scientists call it a sort of conveyor belt – there's constant motion and change, but the total surface area of the Earth remains the same.

There are a few theories about what makes the plates move. The lithosphere is much denser than the asthenosphere, so we understand why it can slide, but where does the energy come from? One view is that it's from dissipating heat in the mantle, but the plates may move due to gravitational pull, forces coming from the Earth's rotation and the gravitational pull from the Moon or the Sun.



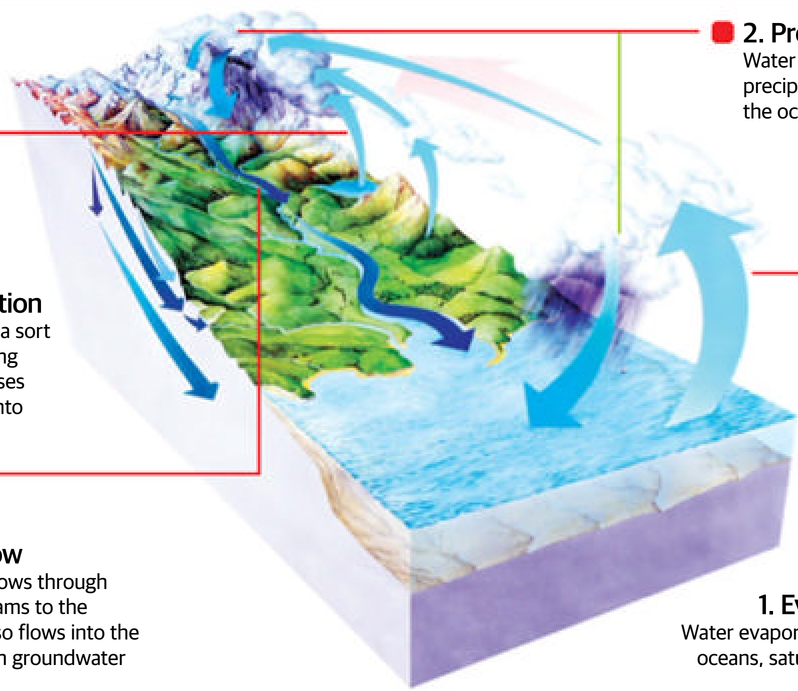
Mountains form when tectonic plates undergo subduction, folding against each other or raising up sections of the Earth's crust

"Some plates have hot spots – areas of volcanic activity under the mantle within the plate, where volcanoes form"

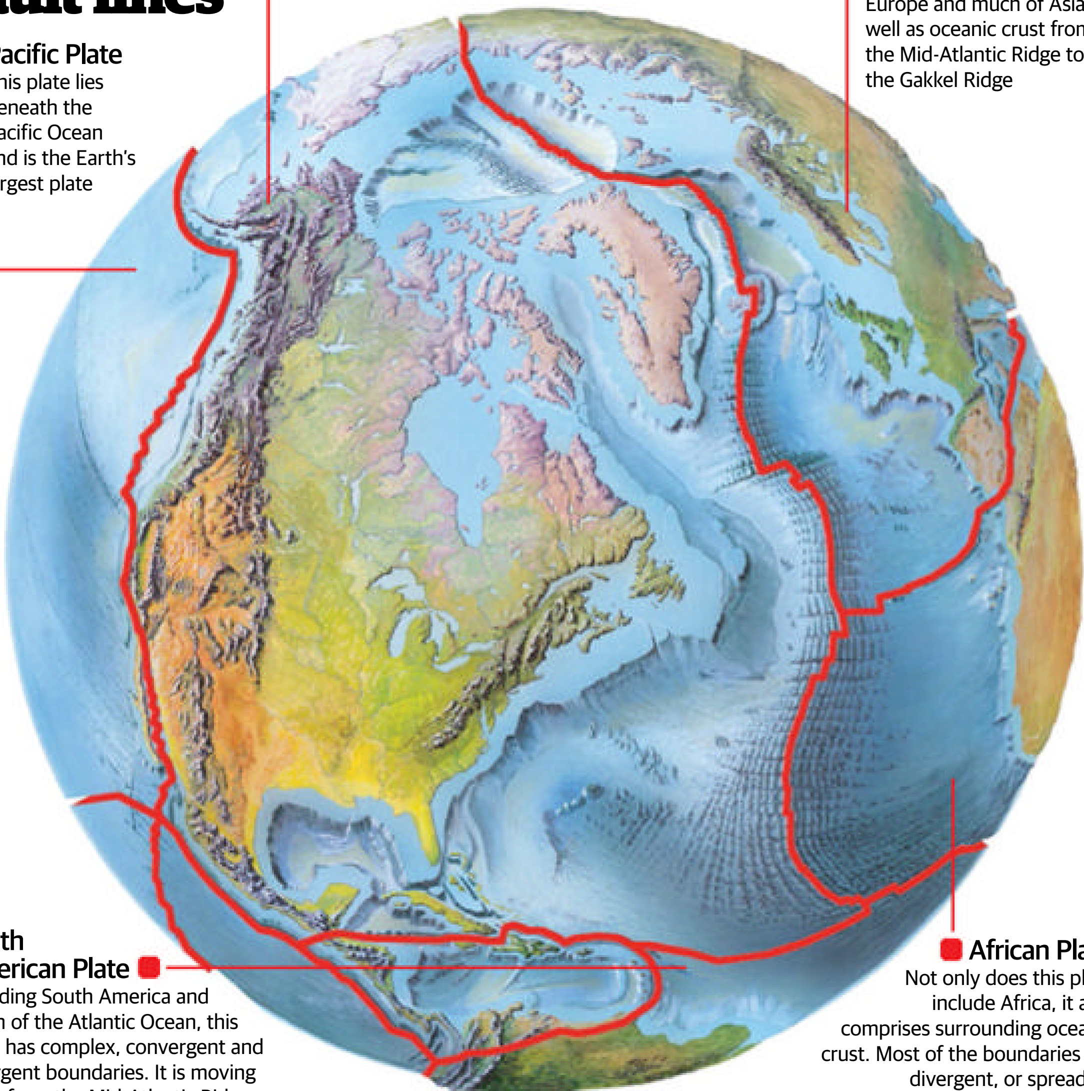
Weather and climate

Energy from the Sun heats the air in the lowest level of our atmosphere, the troposphere, causing it to expand. Warm, lower-density air rises, while cooler, high-density air sinks. This is called atmospheric circulation. Along with the ocean currents, it's responsible for the movement of heat in the air and powers our weather and climate.

The same atmospheric circulation that distributes thermal energy also transports water vapour, present in the atmosphere from evaporation and transpiration. Warm air rises, falling as precipitation. The amount and kind of precipitation depends on temperature and other features. Once it falls, it replenishes oceans, lakes and groundwater, some of which rises again through evaporation. This is known as the water cycle.



Earth's fault lines



Pacific Plate
This plate lies beneath the Pacific Ocean and is the Earth's largest plate

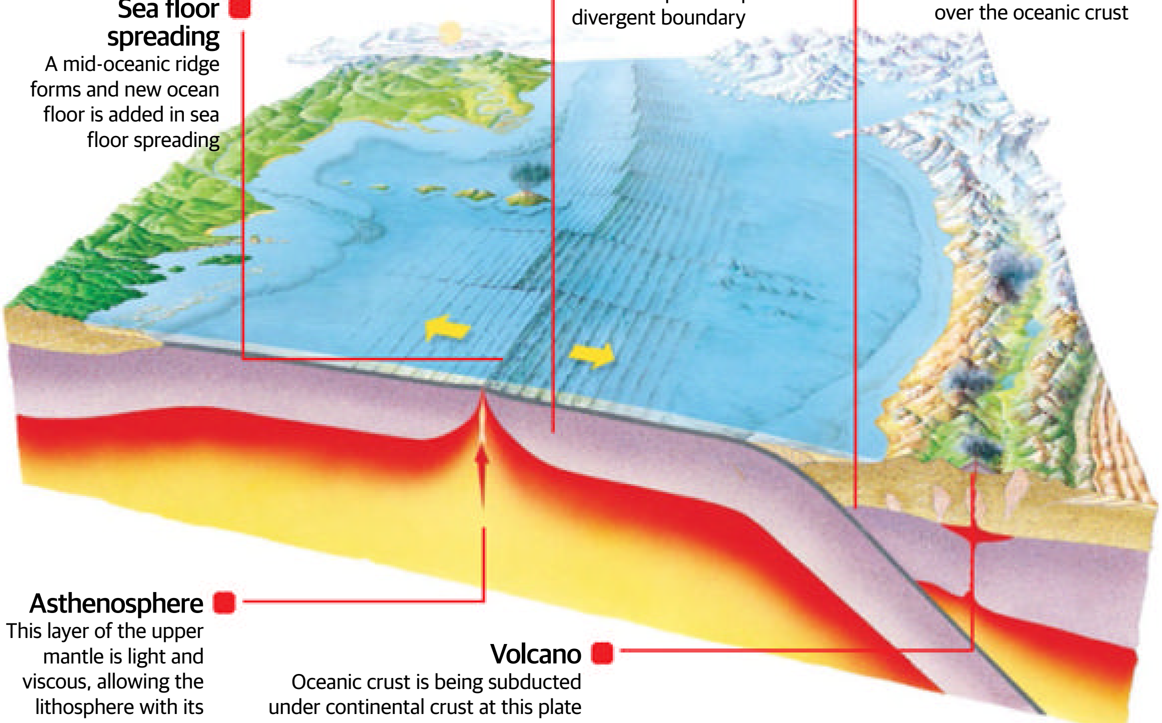
North American Plate
This plate extends from the Mid-Atlantic Ridge along the floor of the Atlantic Ocean to the Chersky Range in Siberia. It has divergent, convergent and complex boundaries

Eurasian Plate
This plate includes all of Europe and much of Asia as well as oceanic crust from the Mid-Atlantic Ridge to the Gakkel Ridge

South American Plate
Including South America and much of the Atlantic Ocean, this plate has complex, convergent and divergent boundaries. It is moving away from the Mid-Atlantic Ridge

African Plate
Not only does this plate include Africa, it also comprises surrounding oceanic crust. Most of the boundaries are divergent, or spreading

Plate tectonics



Sea floor spreading
A mid-oceanic ridge forms and new ocean floor is added in sea floor spreading

Oceanic crust
The dense oceanic crust of these two plates is part of a divergent boundary

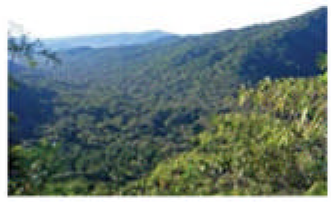
Continental crust
The lighter, thicker continental crust lies over the oceanic crust

Asthenosphere
This layer of the upper mantle is light and viscous, allowing the lithosphere with its plates to move on top

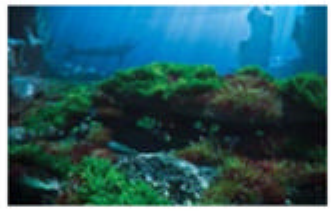
Volcano
Oceanic crust is being subducted under continental crust at this plate boundary, resulting in volcanoes

Surface features

Desert
Deserts get so little precipitation that they can't support much life, but there are desert-dwelling plants and animals. A true desert gets less than 400mm (16in) of rainfall per year. They make up about one-third of the Earth's land surface.



Rainforest
Rainforests have very high levels of rainfall, usually a minimum of 1,750mm (68in) each year. They cover 5% of the Earth and are the source of about 25% of our natural medicines, and home to millions of species of plants and animals.



Oceans
Saline or saltwater makes up about 71% of the Earth's surface. No other observable planet has as much water on its surface. The total volume of saltwater on Earth is approximately 1.3 billion cubic kilometres (311 million cubic miles).

Ice caps
Ice caps and glaciers cover about 10% of the Earth's surface, and hold about 70% of our freshwater. Glacier movement helped shape the topography of the land in many areas. If they all melted, our ocean levels would rise by 70m (230ft).

Why is there life on Earth?

The Earth has the perfect recipe to support life. But why?

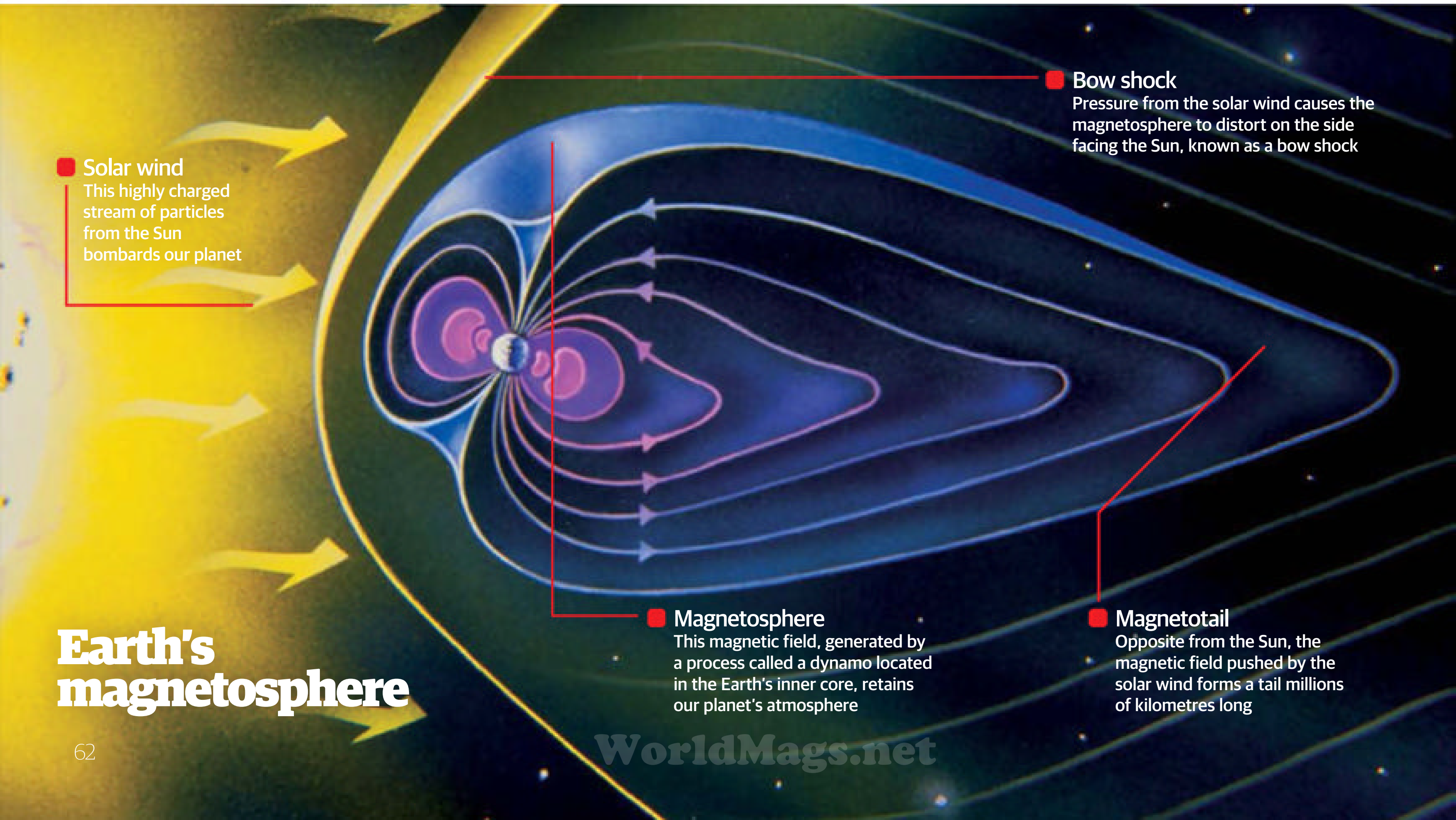
Astronomers have coined the term 'Goldilocks Zone' to describe star systems that theoretically have planets with atmospheres capable of retaining water. All known forms of life require liquid water, so this has become the gold standard for finding life on other planets. They may also be called circumstellar habitable zones (CHZ). But a planet needs more than just water – other bodies within our Solar System are believed to have it but we still haven't found life there. Earth is 'just right' for a number of reasons.

The atmosphere is one. All known forms of life require oxygen-rich air, and our atmosphere is full of it. It's being continually replenished by plant respiration and by the water cycle. Thanks to the Earth's gravity and its magnetic field, the atmosphere stays put and hasn't been swept out to space. Our Sun is also an important factor, because the Earth is the perfect distance from it, with temperatures and heat levels that, while varied, allow life to grow and thrive. Sunlight is also necessary, because without enough sunlight, plants on the Earth would not be able to photosynthesise.

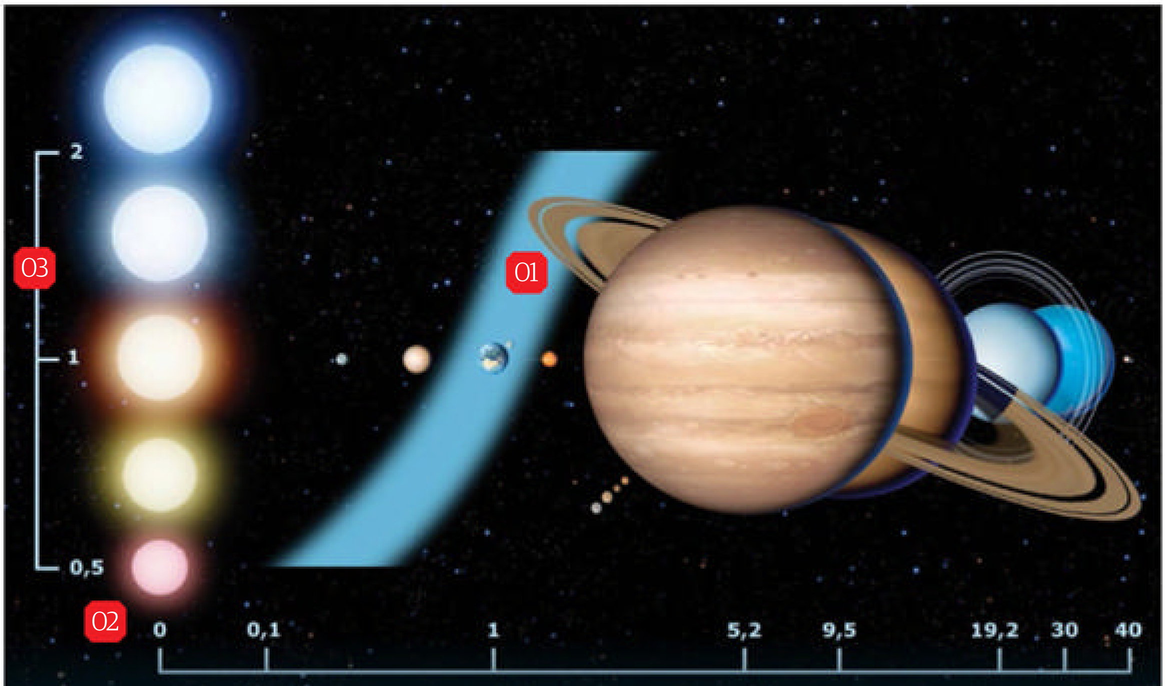
The water cycle, proximity to the Sun, sunlight and atmosphere all contribute to a suitable climate for life. While temperatures vary across the globe, Earth doesn't experience the extreme swings of other planets. On Mars, it can be as warm as 25 degrees Celsius (77 degrees Fahrenheit) but as cold as minus 140 degrees Celsius (minus 220 degrees Fahrenheit).

Water

Although other planets have been found to have water, none have as much as Earth. Sometimes our water mass, including the oceans and freshwater sources, is known as the hydrosphere. Without such plentiful sources, the water cycle could not function and there wouldn't be enough oxygen to support life. Human bodies comprise about 70 per cent water, and life on Earth needs it to survive.



Earth's magnetosphere



The Goldilocks Zone

1. Habitable Zone
This narrow band shows that Earth is the only planet in our Solar System known to be capable of sustaining life.

2. Radius of planet's orbit relative to Earth
Earth is at '1'. The other planets are too big or too small to support life.

3. Stellar mass relative to the Sun
The Sun also has the perfect mass of any known star to provide the right amount of light and energy to the Earth.

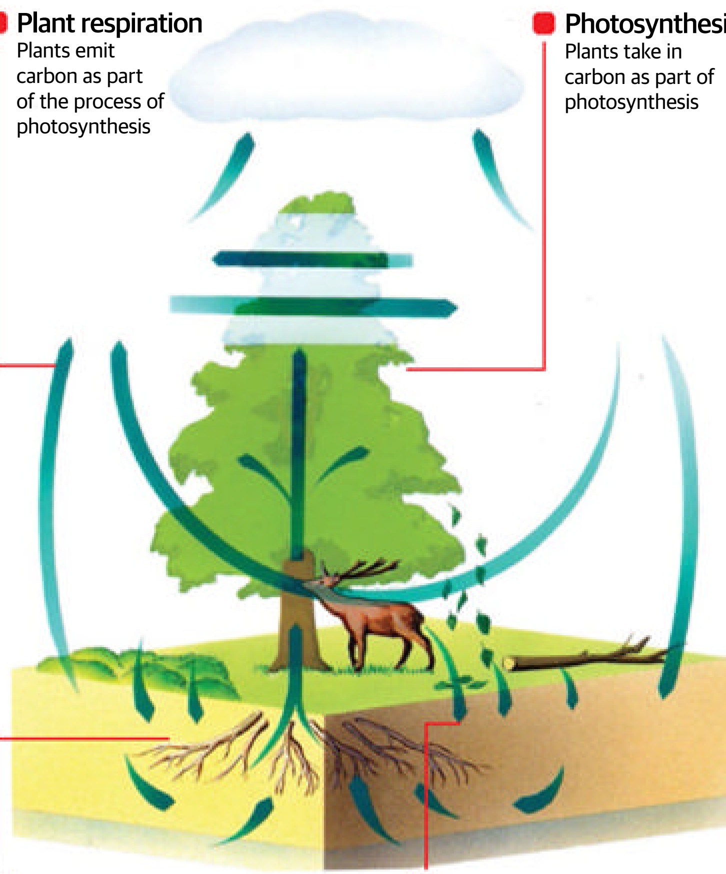
Carbon

The carbon cycle is just as important to our climate and survival on this planet as the water cycle. Carbon dioxide is an element of the greenhouse effect, which traps heat in and keeps our planet at a regular temperature, maintaining our regular climate. Most of the life on our planet is carbon-based, with this abundant element bonded to other elements to create the building blocks of life. It is replenished in the atmosphere by plant and microbial respiration, as well as decomposition of organic materials.

> "The atmosphere is being continually replenished by plant respiration and by the water cycle"

Plant respiration
Plants emit carbon as part of the process of photosynthesis

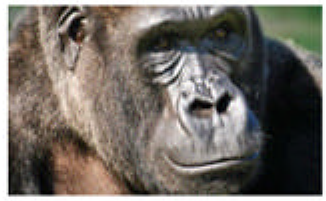
Photosynthesis
Plants take in carbon as part of photosynthesis



Absorption from soil
Plants and trees absorb carbon from the soil

Decomposition
Decomposition of organic waste adds to the carbon in the ground

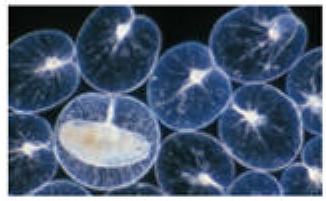
5 kingdoms of life



Animalia
The animal, or Animalia, kingdom (also called Metazoa), includes about 1,000,000 multicellular, heterotrophic species.

Plantae
Kingdom plant, or Plantae, includes everything from multicellular flowers to mosses. There are about 250,000 plant species.

Fungi
Fungi include around 100,000 identified species. The Fungi kingdom includes mushrooms, yeasts and moulds.



Protista
The Protista kingdom has 250,000 species which don't have much in common with each other, apart from not belonging elsewhere.

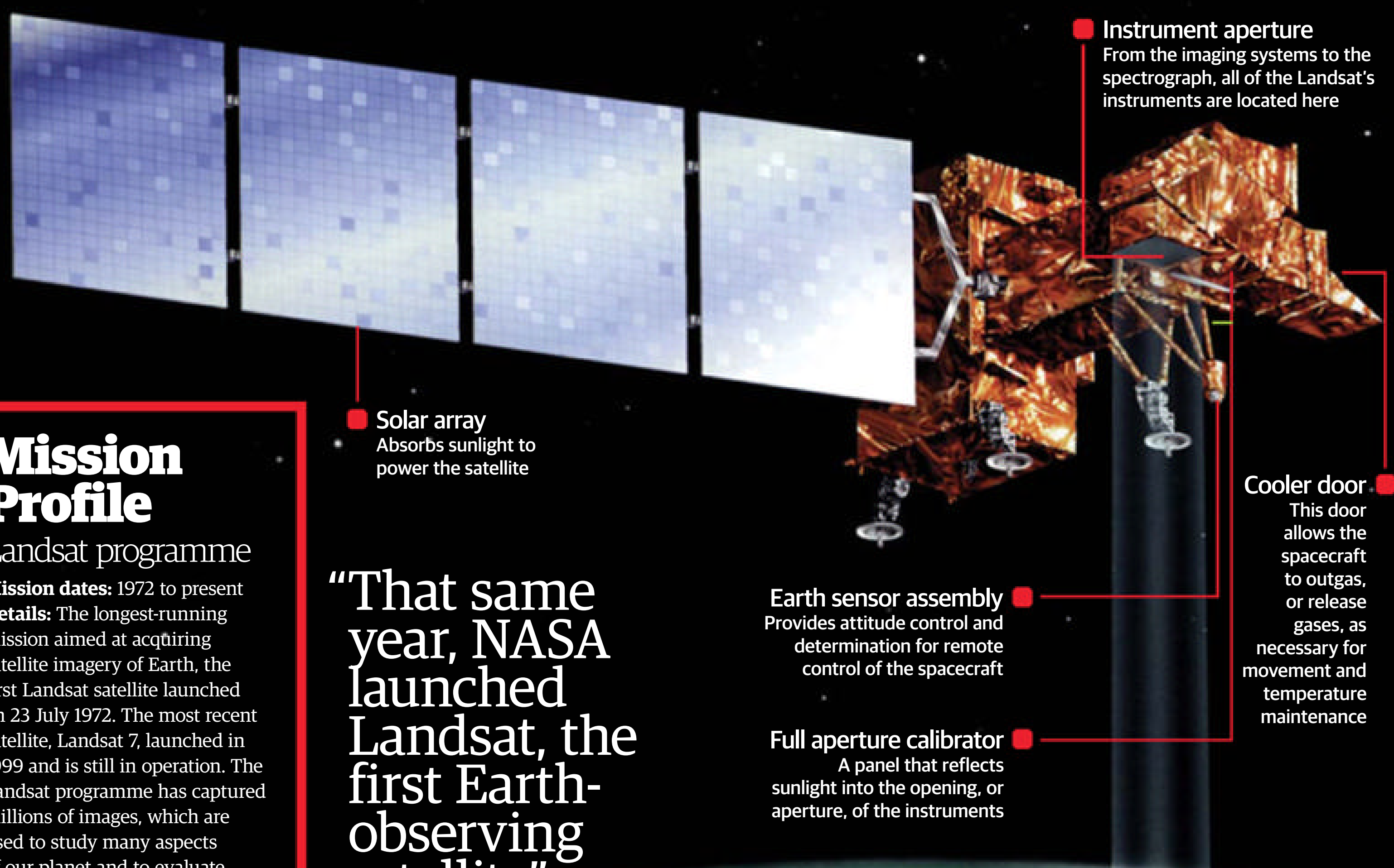
Monera
The Monera kingdom is made up of species such as algae and bacteria. There are approximately 10,000 species in this kingdom.

Observing Earth

Checking out our home planet has become easier over time

Until we were able to get far enough away from our planet to view it, the only way we could infer things about it was by exploring its relationship to other heavenly bodies. And for a long time, what we believed was wrong. Many ancient cultures, for example, believed that the Earth was the centre of the universe. This was based on two observations: the stars and other planets appeared to revolve around the Earth, and to a person on Earth, the planet seemed to be perfectly at rest. Once we were able to better observe other bodies, we began to learn the truth about our home planet. Then we developed the technology to take pictures of the Earth from space. The first such image was taken by a rocket, shot 56 kilometres (35 miles) into the air over New Mexico, USA in 1946.

We've come a long way since then. The Freedom 7 spacecraft, carrying the first American into space, went up in 1961 and returned some amazing images of the Earth's surface. But the first fully illuminated photo of Earth was taken by astronauts aboard the Apollo 17 spacecraft in 1972. Known as 'The Blue Marble', it became one of the first photos to be widely distributed. That same year, NASA launched Landsat, the first Earth-observing satellite. It continues to operate today, sending back images that have been used in everything from agricultural planning to national security. Today there are dozens of Earth-observing satellites – some commercial, some sent up by NASA, the ESA or other space agencies around the world. These satellites don't just take pictures; they monitor the weather, climate and environment. Geostationary Operational Environmental Satellites (GOES), for example, are a system of satellites that have been used in meteorology and weather forecasting since 1975. The latest Earth-observing satellite, Suomi NPP (Suomi National Polar-orbiting Partnership), is a joint project between NASA, the NOAA (National Oceanic and Atmospheric Administration) and the Department of Defense. Launched in 2011, it is part of a new generation of satellites and is used to track weather, climate and other environmental changes.



Mission Profile

Landsat programme

Mission dates: 1972 to present

Details: The longest-running mission aimed at acquiring satellite imagery of Earth, the first Landsat satellite launched on 23 July 1972. The most recent satellite, Landsat 7, launched in 1999 and is still in operation. The Landsat programme has captured millions of images, which are used to study many aspects of our planet and to evaluate the changes caused by natural processes and human practices.

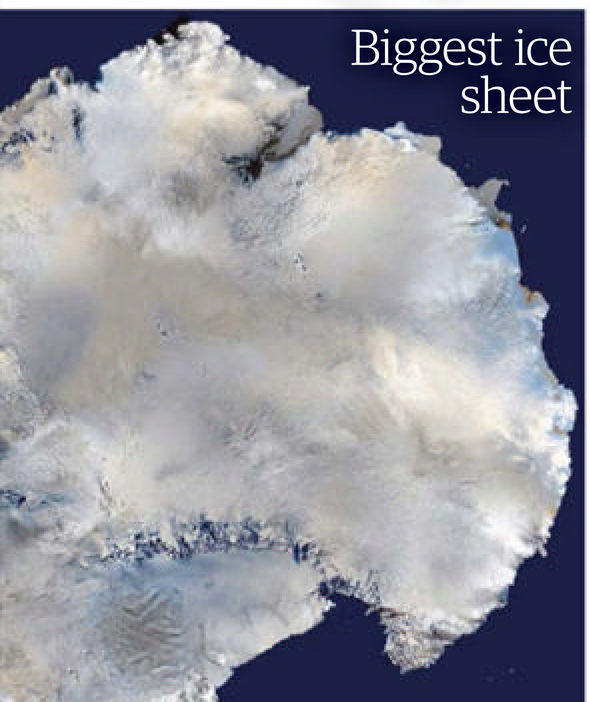
"That same year, NASA launched Landsat, the first Earth-observing satellite"


Highest mountain


Largest rainforest


Biggest active volcano


Largest glacier


Biggest ice sheet

8 stunning Earth landmarks

Largest rainforest
One in ten of the world's known species live in the Amazon rainforest.

Biggest active volcano
Mauna Loa in Hawaii is the largest active volcano on Earth in terms of volume and area.

Tallest waterfall
Situated in Venezuela, Angel Falls stands at 979m and is the world's highest uninterrupted waterfall.

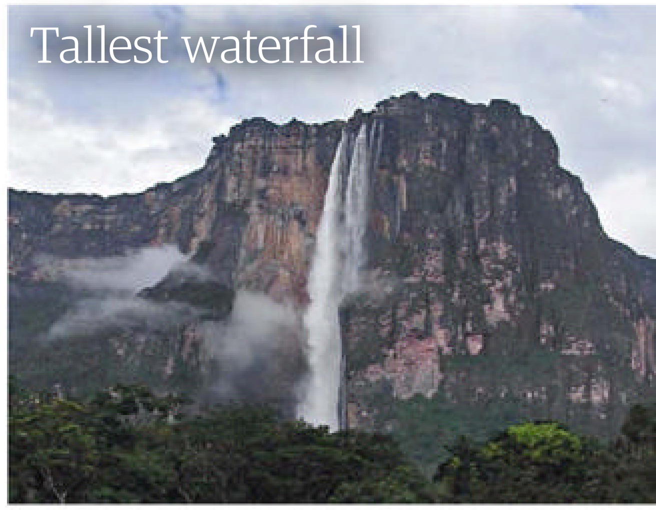
Biggest crater
With a 300km diameter, the Vredefort crater in South Africa near Johannesburg is Earth's largest known impact crater.

Deepest canyon
The Tsangpo Canyon in Tibet can reach depths of over 6,000m.

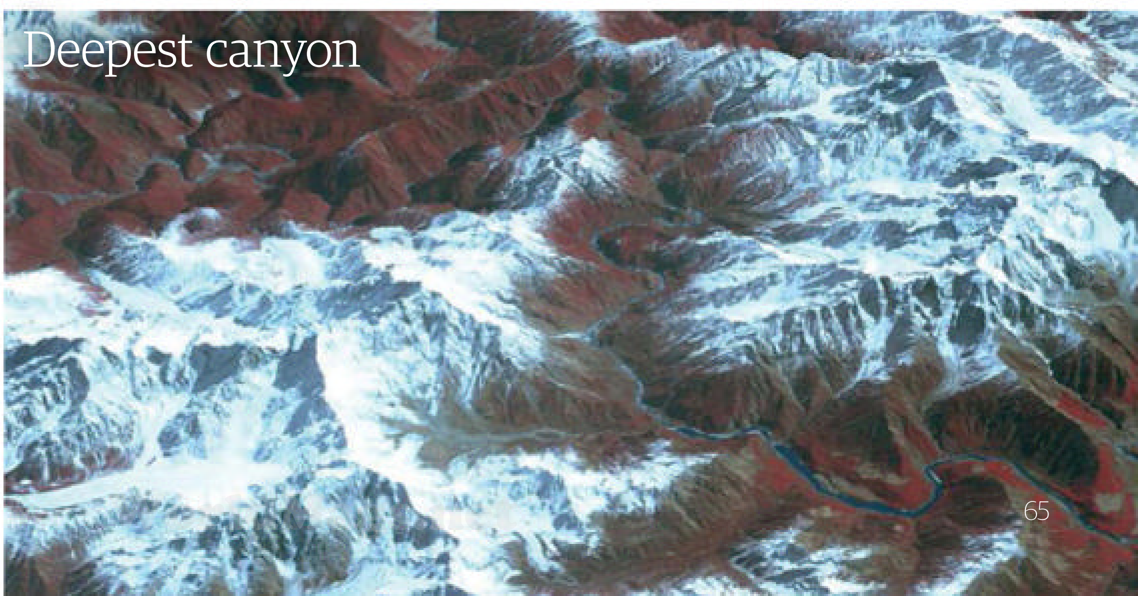
Biggest ice sheet
The East Antarctic Ice Sheet is the largest ice sheet on the planet and is home to the South Pole.

Largest glacier
Antarctica's Lambert Glacier is about 100km wide, over 400km long and about 2,500m deep.

Highest mountain
At 8,848m tall, Mount Everest is the highest mountain on Earth.


Tallest waterfall


Biggest crater


Deepest canyon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OUTPOST EARTH

From spacewalking in water to living in the desert, we look at how astronauts train for the challenges of exploring moons, asteroids and planets on Earth

On 4 November 2011, six triumphant men from across the world returned to Earth and emerged from a windowless isolation chamber to elated cheers. They had – in theory at least – been to Mars and back on a journey that had taken them away from their friends and families for 520 days. During that time, three crew members had spent 30 days on the Red Planet, having detached from their mother ship to explore the Martian surface, removed soil and rock samples and planted three flags; one each for the Chinese, Russian and European space agencies.

Their time away proved tough. The mission affected their sleep patterns, with one crew member's body falling into a 25-hour day cycle. And although they had books, DVDs and the videogame *Guitar Hero* to occupy them, they had become bored and demotivated by the monotonous journey. Their activity levels lowered, their body temperature dropped by an average of 0.4 degrees Celsius (32.7 degrees Fahrenheit) and they were at risk of bone and muscle wastage. They may have lived in harmony but the three Russians, two Europeans and one Chinese were, it could be surmised, spaced out at least some of the time.

And yet the six hadn't actually ventured away from Earth at all. Their spacecraft was nothing more than a series of steel tubes at the Russian Institute for Biomedical Problems in Moscow. The landing module was also a cylinder that had been made to feel like a Mars landing ship. The planet surface was simply a large room with a high, domed ceiling and a floor covered by red sand and rocks over which the crew had walked dressed in Orlan spacesuits. Everything had been a test, albeit one carefully constructed to be analogous to the expected isolation and challenge of a round trip to Mars.

Called Mars 500, the analog mission was of great use to scientists, engineers and astronauts preparing for a real-life future mission to Mars. By observing the experience of the crew, examining their physical and mental health and testing new technologies, experts were able to learn many lessons vital for

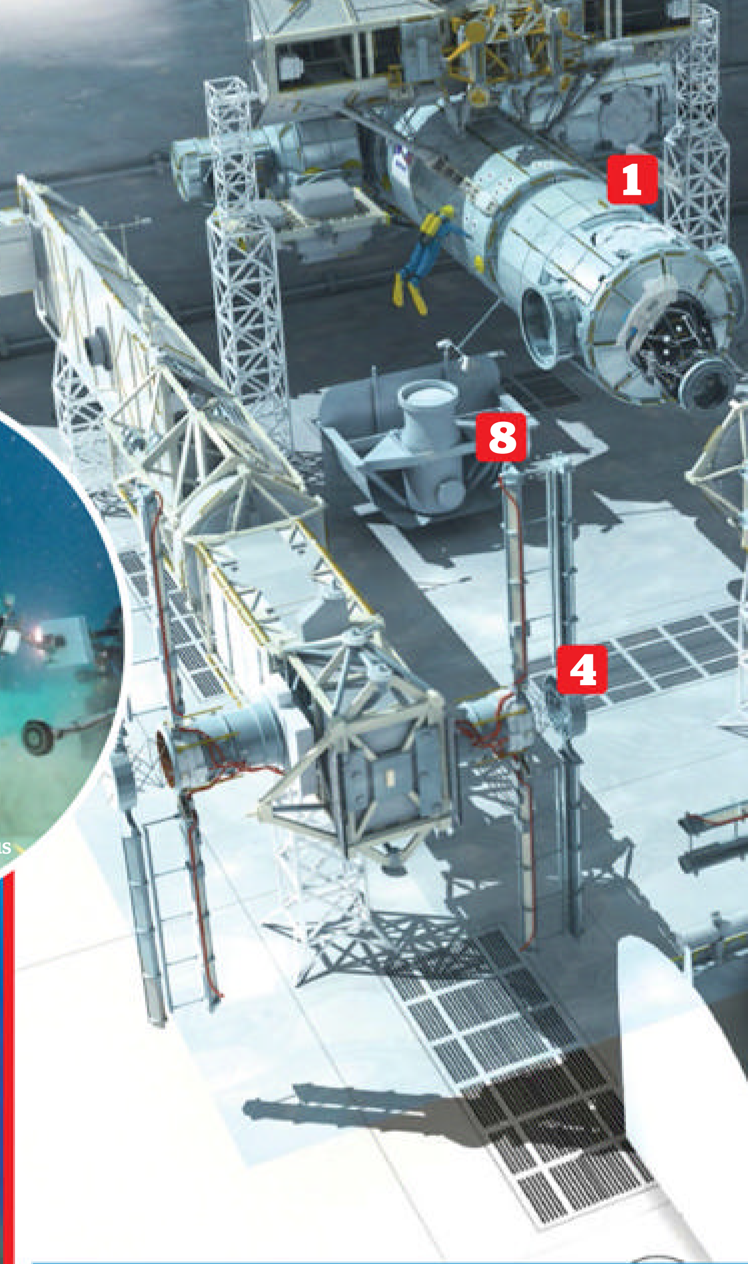
round trips to the Red Planet. "We were able to simulate the isolation astronauts would feel," explains Jennifer Ngo-Anh, ESA's Mars 500 programme manager. "The main purpose was to study whether, from a survival and interpersonal point of view, we could put a crew of six in a spacecraft for such a long time. We were looking at the psychology of the crew, their social interaction and cultural differences. We wanted to know how they would cope with the life support system we had in place and a limited water supply. The only things that were missing were simulations for microgravity and radiation."

Mars 500 is one of many analog missions - some of which also create artificial, simulated conditions. But analog missions also make use of the extreme environments found on Earth. One such mission is NEEMO, or NASA Extreme Environment Mission Operations. It involves sending six aquanauts to live underwater in a laboratory called Aquarius, some 5.6 kilometres (3.5 miles) from the shore of Key Largo in Florida. There they are isolated but they also get to experience reduced gravity in what is the world's only operating undersea lab.

Aquanauts can spend as long as three weeks on a NEEMO mission, living and working underwater. For missions on the bed of the ocean, they wear diving suits and oxygen tanks in place of spacesuits. They embark on seawalks that, just like a spacewalk, are carefully planned and restricted in time. Their mobility is slowed and their movement is difficult, mimicking the effort they would need to make when exploring a planet like Mars. In doing this, NEEMO is able to simulate Moon and asteroid missions, testing equipment and operational concepts.

Training for microgravity

The Neutral Buoyancy Lab facility is a large indoor pool that contains full-sized mock-ups of the International Space Station



NASA Extreme Environment Mission Operations (NEEMO) trains astronauts at the Aquarius submarine station

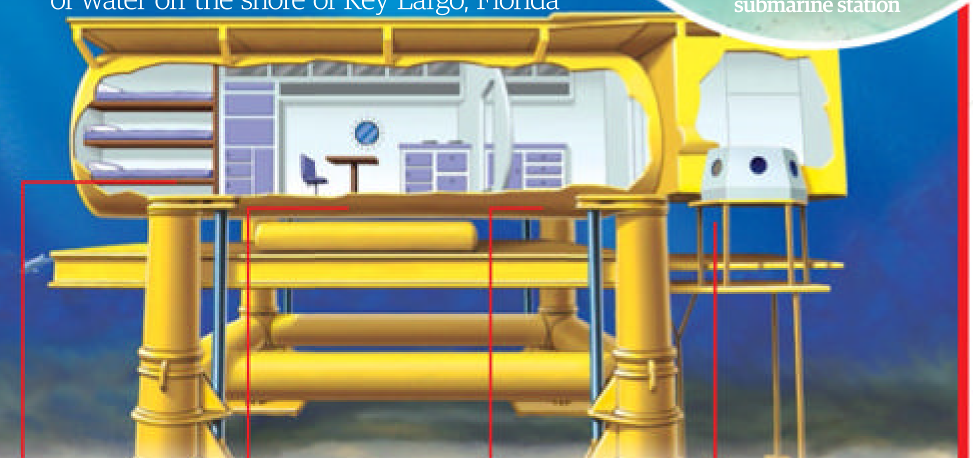
1. The US lab
A replica of the ISS still doesn't fit directly into the pool. It is bent into the so-called wishbone configuration we see here.

2. P6 segment
By allowing astronauts to view the segments of the ISS's truss (backbone), they can familiarise themselves with its structure.

3. Cargo bay
This part of the ISS mock-up shows the cargo bay of the Space Shuttle Orbiter, which is used to deploy to or retrieve payloads from Earth.

Asteroid mission preparation

Aquarius is the world's only submarine research station, found in 19 metres (62 feet) of water off the shore of Key Largo, Florida



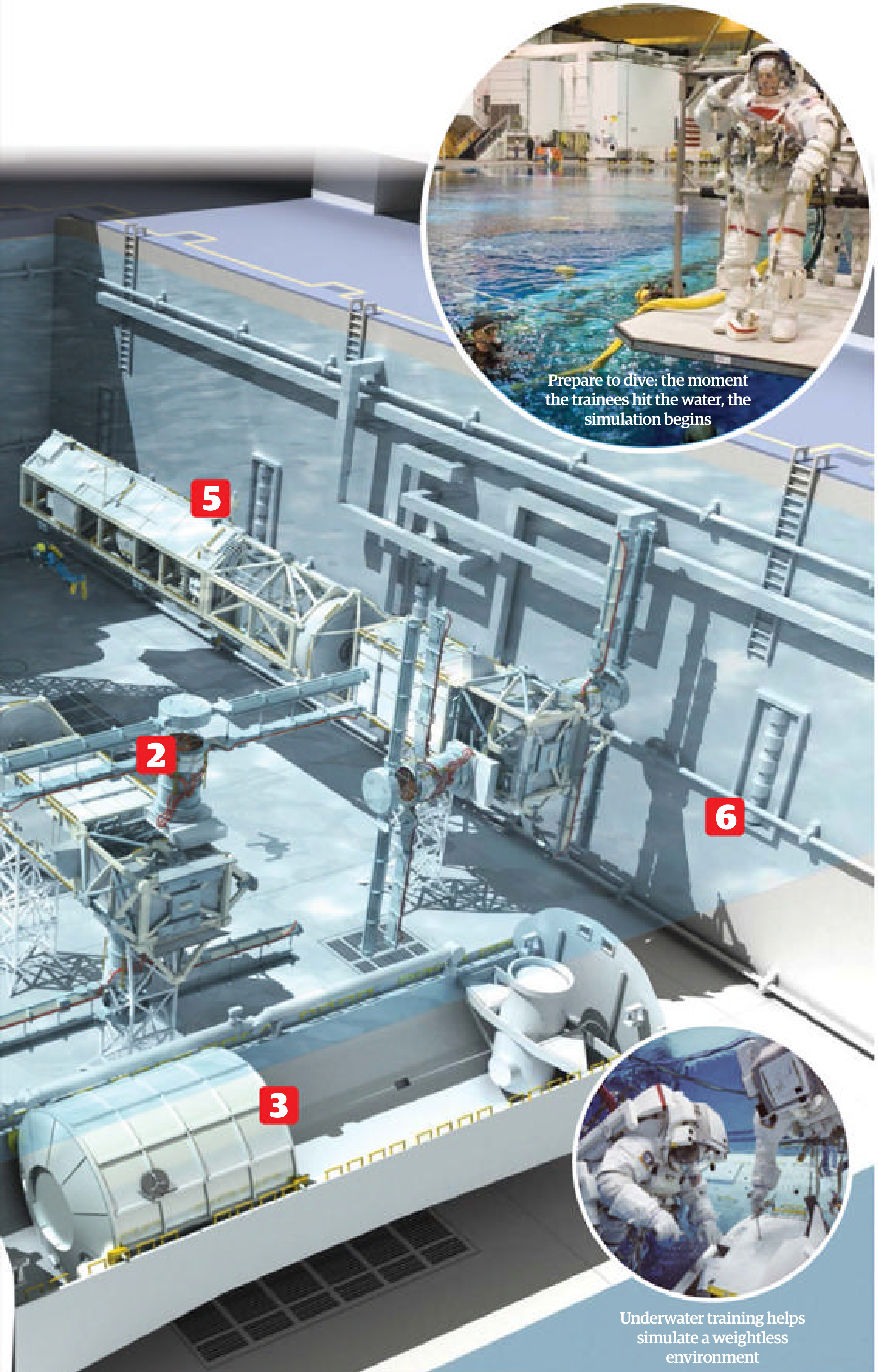
Aquanauts
Six aquanauts live and work in pressurised conditions for up to three weeks. They sleep on bunks and have an ocean view

Cramped space
Aquarius is an 85-ton, double-lock, sub-aquatic laboratory. The main lock contains a kitchen and relaxation space

Science area
The entry lock includes workstations and life support. It houses lab equipment and a toilet that connects to a sewer

Wet porch
Aquanauts come and go via the wet porch, which is open to the ocean. Aquanauts need 15 hours of decompression on exit

Prepare to dive: the moment the trainees hit the water, the simulation begins



Underwater training helps simulate a weightless environment

4. S4 segment
As astronauts approach these segments underwater, they will experience the weightless environment of space.

5. P1 segment
Water is the best environment for spacewalk training on Earth. Being able to move in their suits, use handrails and pass objects is vital.

6. NBL tank
The Neutral Buoyancy Laboratory tank is a huge 62 metres (202 feet) long, 31 metres (102 feet) wide and 12 metres (40 feet) deep.

7. The ISS
The ISS is 110 by 73 metres (361 by 240 feet). In the NBL, astronauts can practise installing and maintaining components in space.

8. Docking system
When a shuttle docks with the ISS, it is important that a secure connection is achieved. Astronauts can practise it here.

What is microgravity?

In space, gravity exists but in a reduced form. On the International Space Station, for example, gravity is around 88 per cent of that found on the Earth. But, because astronauts are in free fall, they appear to float. That's because free falling means they are falling towards and yet around Earth. This is thanks to the pull of the Earth and the speed at which the ISS and spacecraft are moving to match the curvature of the Earth. Referred to as microgravity, it can happen inside a spacecraft or outside on a spacewalk. By simulating microgravity, even for a limited time, astronauts can be better equipped for real-life space missions.

Hervé Stevenin

EVA and Zero-G instructor for ESA astronauts

Hervé Stevenin leads ESA's Neutral Buoyancy Facility Operations. With more than 20 years of training experience, he is a spacewalk instructor for European astronauts.

Why is underwater training useful for astronauts?
Astronauts have to perform EVAs and so we need an environment of weightlessness. Although we can use reduced gravity aircraft, they only give astronauts 23 seconds of pure weightlessness or microgravity. This is not appropriate for EVAs because they are six hours long and astronauts have to work on modules and in a complex environment. So we use an underwater environment to simulate the weightlessness and the astronauts feel like they are in a controlled buoyancy environment.

How closely can simulation match real life?
The astronauts can work in a big water tank, into which we submerge big modules of the station. The modules are full scale and they have all of the EVA-related equipment like handrails on them. The astronauts can use the same kind of tethers and tools for the work underwater that they would carry out in space outside a station so it's equally demanding psychologically and physically. We teach astronauts to be efficient in the way they work. They need to be aware of the environment and communicate well. Not all astronauts can do an EVA: NASA and the Russians put all astronauts through a basic EVA training programme and they then assess who are the best ones. Only the best will continue.

As part of the analog mission, aquanauts will spend a lot of time in a purpose-built habitat. All six will live together in cramped conditions and their ability to work together and support each other is closely studied. Each crew member is trained to deal with fire in the module as well as potential toxicity in the atmosphere.

While two Aquarius technicians are responsible for maintaining the habitat and also live with the astronauts, and while there are safety divers accompanying the crew, part of the analog mission is to limit outside assistance, with communication channels delayed by five minutes. The sense of isolation is also very real: travelling back to the sea surface is arduous and it requires aquanauts to undergo a 16-hour decompression sequence in order to protect the crew members from falling ill with decompression sickness.

"It takes even more time to come back to the surface than it takes to get back from the International Space Station to Earth, so this means the risks are real," says Hervé Stevenin, who was selected to be a crew member of the NEEMO 19 mission in September 2014.

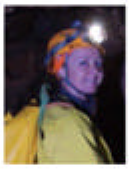
By ensuring there is no quick 'get out', the mission is able to test the resolve of the aquanaut and his or her ability to be an astronaut. They are given a full flavour of the scientific tasks they are expected to carry out too, drilling down into the sea ground to collect samples. Sometimes the crew members are separated and sent to different landmarks, allowing them to recognise geological features of interest to the exploration. They are asked to take distance measurements and the dimensions of items they are studying. They have to send images and video from their helmet cameras to mission control. "It really gives you a feel for what it is like to be a space crew member," says Stevenin, who also leads ESA's Neutral Buoyancy Facility Operations. But it also lets the mission leaders figure what works effectively and what needs to be re-examined.

There are also secondary objectives. Scientists can conduct human physiology experiments during a NEEMO mission, which helps when optimising the planning, technology and expectations of science research during space explorations. With planned human crewed missions to Mars, such analog missions will certainly prove useful when training the next generations of space explorers.

As well as using Aquarius, NASA has an enormous 22.7 million litre (6.2 million gallon) pool located at the Sonny Carter Training Facility near NASA's Johnson Space Center in Houston, Texas. Called

Loredana Bessone

CAVES course and mission director



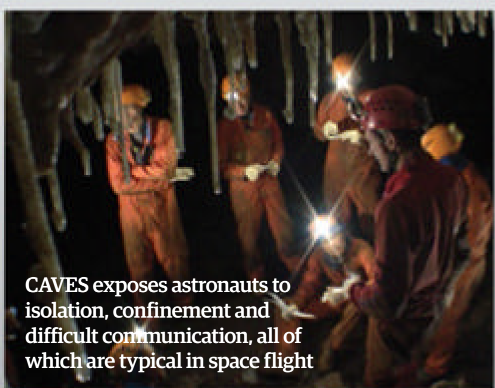
Loredana was hired by ESA for a student job in 1990 and within a few years had begun work on human space flight. She went on to develop astronaut operational skills training including ESA's CAVES.

What were you looking for when you developed CAVES?

I was looking for an environment very similar to that which astronauts would encounter during human space flight so I wanted isolation, confinement, limited resources and difficult communication. There had to be real risk to create stressors that are typical on human space flight and a real mission that would allow astronauts to work together effectively and safely as an international team.

How can you be sure simulations match real life experiences?

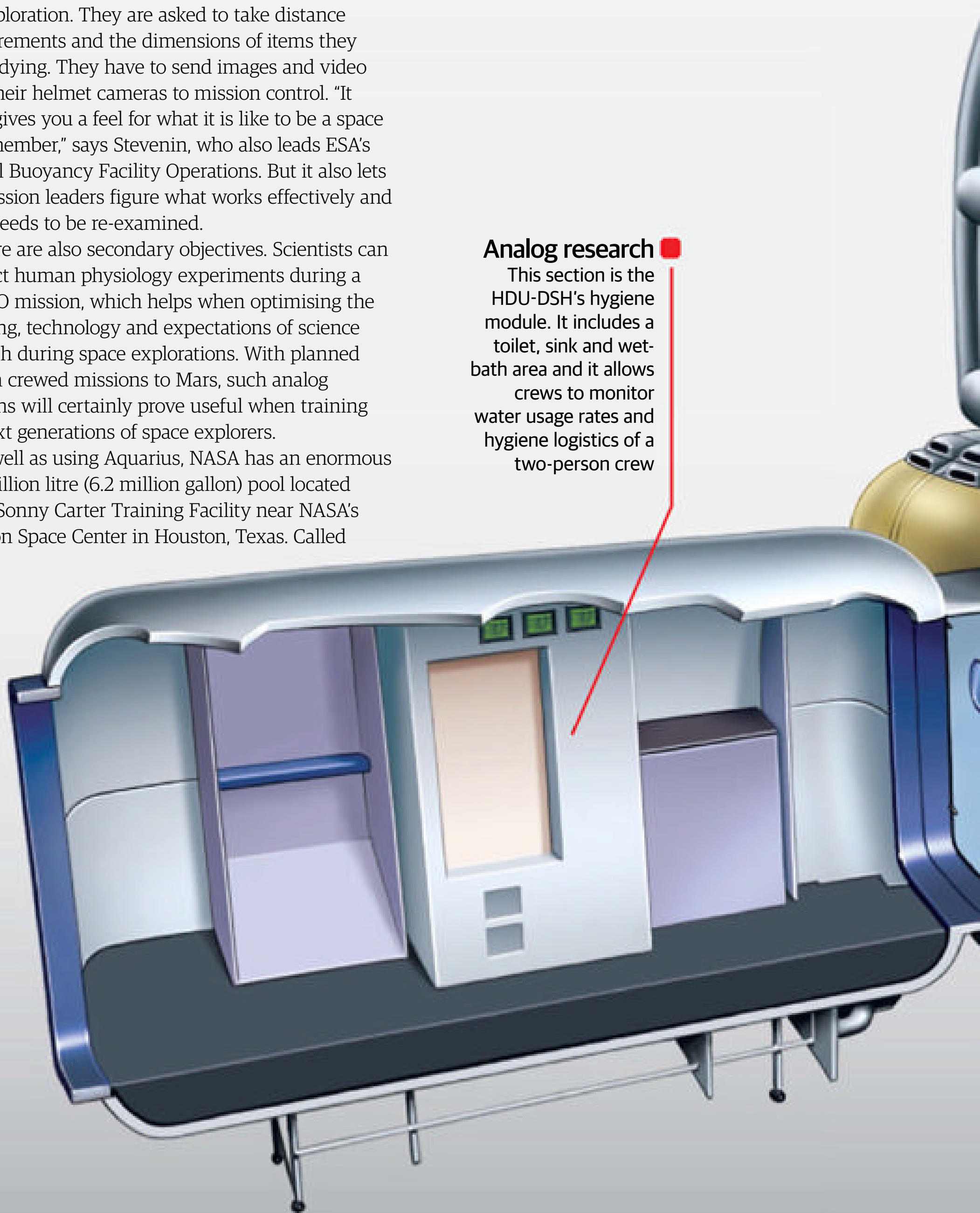
CAVES is a good analog. If anything, it can be even worse in a cave; more isolating than on a space station. Communication is achieved by a wire up to the base camp but if you just twist an ankle or a wrist you have to be carried out. You have to pay attention to everything you do because you only have the very limited visibility given by your headlamp. It's just like on an EVA where astronauts have limited visibility through their helmet. You can get disorientated so it is very important to have situational awareness at all times.

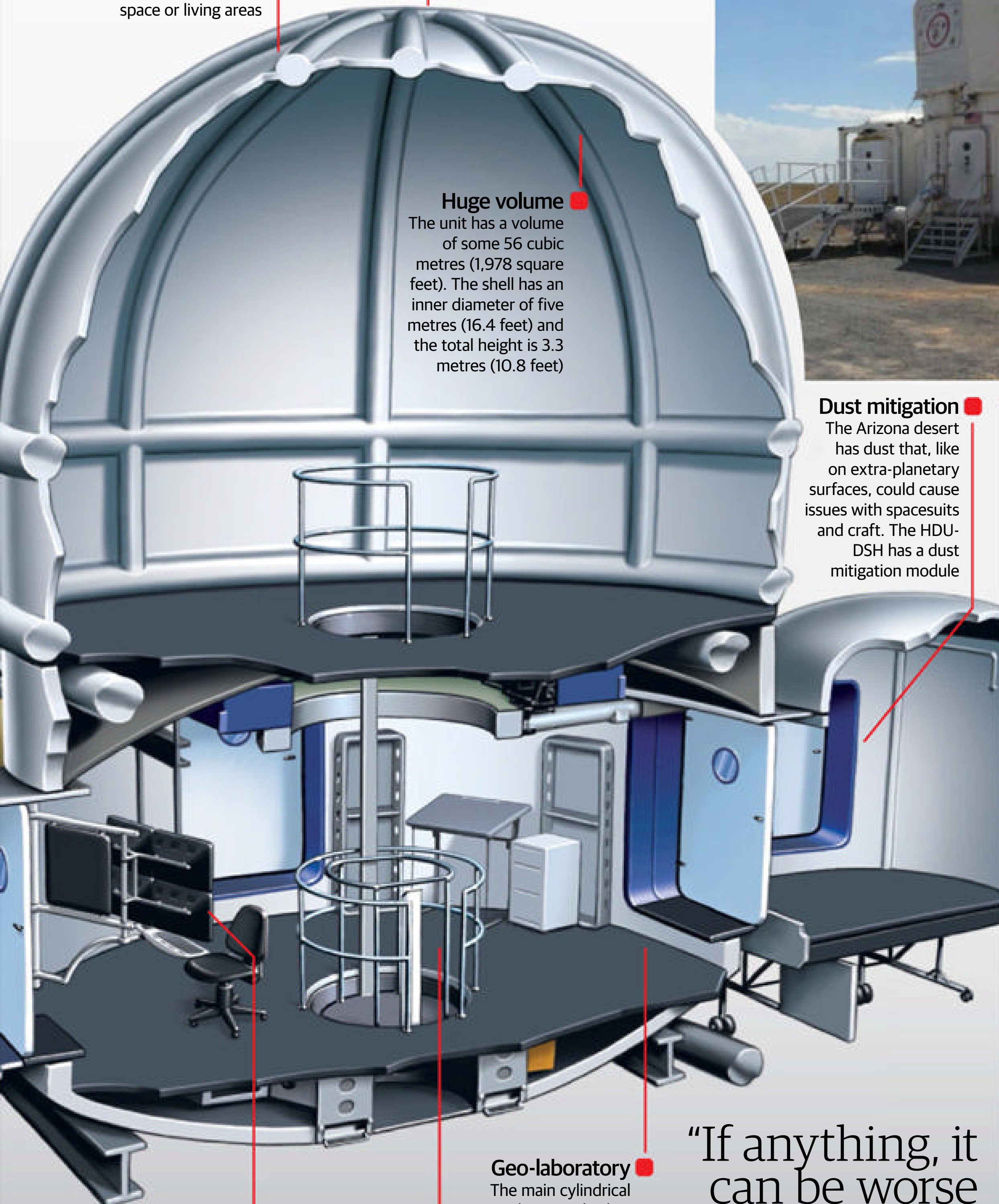


CAVES exposes astronauts to isolation, confinement and difficult communication, all of which are typical in space flight

The Deep Space Habitat

Analog research from Desert RATS (Desert Research and Technology Studies) enables NASA architects, engineers and scientists to create the perfect space base





The shell
The shell of the Habitat Demonstration Unit – Deep Space Habitat (HDU-DSH) has space for an inflatable loft. This allows the astronauts to create additional laboratory space or living areas

Material make-up
The prototype unit shell is made of composite fibreglass resin. It is attached to eight steel ribs, each of which is just 0.8 centimetres (0.3 inches) thick

Huge volume
The unit has a volume of some 56 cubic metres (1,978 square feet). The shell has an inner diameter of five metres (16.4 feet) and the total height is 3.3 metres (10.8 feet)

Dust mitigation
The Arizona desert has dust that, like on extra-planetary surfaces, could cause issues with spacesuits and craft. The HDU-DSH has a dust mitigation module

Work space
Since the HDU-DSH is an operational base, it allows astronauts to process geological samples and perform scientific experiments

A lift
To enable astronauts to move up to the second level, there is a lift in the centre of the unit

Geo-laboratory
The main cylindrical work space also has a geo-lab, a general maintenance workstation and medical operations. The space is broken into clearly defined segments

Desert RATS helps prepare astronauts for carrying out tasks and experiments on Mars, the Moon and asteroids

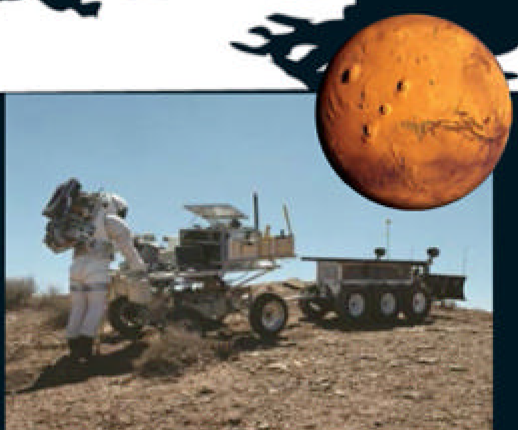
Desert RATS training

Located by a 2-million-year-old lava flow near Flagstaff, Arizona, Desert RATS conducts annual missions, with an emphasis on testing roving and spacewalks. They test for optimum crew sizes and the science that can be conducted on Mars, the Moon or other rocky bodies. It has experimented with backpacks and arm-mounted computers and it has introduced cutting edge robots. It has also experimented with surface networking and spacesuits that can use speech recognition to control suit parameters or the movement of robots. Any technology trialled one year is refined and tried again the next. The six-legged ATHLETE all-terrain vehicle has been chopped back to three legs, for example, and retested.

> "If anything, it can be worse in a cave than on a space station"
> **Loredana Bessone, CAVES mission director**

Where in the world?

The training facilities across the globe that prepare astronauts for extra-terrestrial expeditions



1. Desert RATS
Flagstaff, Arizona

Desert Research and Technology Studies (Desert RATS) makes use of the Black Point Lava Flow site in Arizona which shares a host of environmental and terrain similarities with Mars, the Moon and near-Earth asteroids. As well as understanding how rovers can cope with craters, slopes, dust storms and volcanic ash fields, it also looks at the tasks that would be better suited to humans such as sample collection.

2. In-Situ Resource Utilisation
Mauna Kea, Hawaii

When astronauts in the future land on the Moon, they would, ideally, be able to produce their own oxygen from lunar rocks and soil. This dormant volcano has proven to be a perfect simulation of the Moon's polar regions. Scientists have studied the effectiveness of rovers to produce oxygen in such a harsh, dusty environment. It's a complex process so it's vital to be able to test the systems here on Earth first.

3. NEEMO
Off the coast at Key Largo, Florida

Astronauts need to be prepared for a hostile, reduced-gravity environment and all of the risks that poses. NEEMO places six astronauts in isolation underwater. It assesses their physiology, psychology and nutrition and it teaches them the benefits of teamwork. Since the water constrains mobility, astronauts also get a good understanding of what an EVA on a planet or asteroid would be like.

4. CAVES
Sardinia, Italy

When astronauts perform EVAs on the International Space Station, they need to be able to operate while tethered and to carry out repairs, under pressure, in the dark and with limited visibility (as happened in December 2013 when a damaged cooling pump needed a repair). CAVES works on the leadership, decision-making, problem-solving and teamwork skills of cavenauts in isolated darkness.

5. Mars 500
Russian Academy of Sciences' Institute of Biomedical Problems, Moscow, Russia

To send a human crew to Mars will take a long journey of some 245 days each way. With a few people in a confined space, it's important to protect their mental and physical health. Mars 500 simulated a 520-day Mars mission, giving three volunteer crews between 2007 and 2011 the opportunity to live and work in a mocked-up spacecraft.

6. Haughton Mars Project
Devon Island, Nunavut, Arctic Canada

Smart rovers, in particular, are useful for scouting sites before humans arrive and for collecting surface geology data. The remote isolation of the Haughton crater research station can help with the exploration of a Martian environment. Its unpredictable terrain is perfect for testing rovers and for astronauts: they can practice changing into a spacesuit from a pressurised vehicle while avoiding dust from entering.

"The astronauts have to do body checks, remain attached to ropes and work together with their teammates" Loredana Bessone

the Neutral Buoyancy Laboratory, it isn't a mission as such but a training exercise and yet it contains a mock-up of the International Space Station (ISS) modules and payloads and it allows for the simulation of weightlessness. Astronauts who intend to work on the ISS can familiarise themselves with the station's segments in an environment near identical to the real-life situation.

To simulate the weightless condition experienced during flight, astronauts need to maintain neutral buoyancy within the pool in order to avoid sinking or rising within the water. "This is the only way to experience weightlessness on the ground," says Stevenin. To do this, the astronaut's body must have an average density equal to the density of the fluid. It is achieved by adjusting the weight of the diving suit. By simulating microgravity and rehearsing spacewalks (or extra-vehicular activity (EVA) as they are known), the astronauts are able to experience some of the conditions they would experience when tending to the exterior of the ISS.

For the unimaginably cold temperature of space, the temperature at the Concordia Station in Antarctica can drop to -80 degrees Celsius (-112 degrees Fahrenheit). It is a useful analog for long duration deep space missions due to its confinement and extreme isolation. During the dark winters, the crew can be without hope of escape or deliveries for nine months. Scientists test for sleep disruption, telemedicine (medical advice via phone or internet), circadian rhythm and, thanks to the air pressure being equivalent to the top of Mount Fuji in Japan, chronic hypobaric hypoxia – a condition that arises from the body being deprived of sufficient oxygen.

As such, within each analog mission, small advances are invariably made, allowing plans to be revised and retested, with each meticulous detail noted so that scientific observations are at their most productive. The In-Situ Resource Utilisation (ISRU) analog mission in Mauna Kea, takes place at a dormant volcano in Hawaii, for instance. It has developed and tested mining equipment and production facilities to produce oxygen, fuel and water in-situ. The volcano helps to simulate the conditions of astronomical objects such as Mars and the Moon. It is hoped that, by introducing and examining new techniques, this analog mission will help reduce the amount of materials that need to be carried into space from Earth.

Analog missions are vital in this regard. Many of them put astronauts through challenging situations and by studying their behaviour and testing equipment or operational concepts, real-life missions can be refined for the benefit of the astronauts, research and productivity.

This is certainly true of ESA's CAVES (Cooperative Adventure for Valuing and Exercising human behaviour and performance Skills). It is a two-week course which teaches astronauts to explore the Sa Grutta caves in Sardinia, Italy. The emphasis is on astronauts working as a multicultural crew in a critical environment, re-creating spaceflight stressors while performing real scientific and exploration tasks.

Many of the procedures used underground are very similar to those on the ISS, with the same standards, formats and terminology. CAVES also trains astronauts to select samples and it assists them in the techniques of identifying the most important. For this reason, CAVES is quickly expanding, with the life science groups of NASA and ESA interested in conducting live science experiments that would accompany another major test site over at Pavilion Lake, British Columbia, Canada. This is a mission that not only lets astronauts assess microorganisms for their scientific value but allows for the testing of robot systems and pressurised underwater vehicles.

In fact, CAVES – which asks participants to live, work and explore in dark, cramped, isolated conditions deep underground – has been built as a combined environmental, scientific and operational analog to human space flight. "It's a very challenging analog mission especially because communication is only made available in selected locations with poor quality," says CAVES course and mission director Loredana Bessone. "The cavenauts cannot come back quickly to the surface either. It takes a few hours to reach the exit in nominal conditions."

For this reason cavenauts must use several techniques to develop situational awareness. They will very often stay close to the walls to orientate themselves. "The astronauts have to do body checks, remain attached to ropes and work together with their teammates," adds Bessone. "And it's a good analog, according to the participants who have been on the course and later flown in space flight. Many consider it to be one of the best if not the best analogs that they have ever been trained on."

Indeed, putting astronauts into such extreme environments can, as a consequence, help their development enormously. The Arizona-based mission Desert RATS (Desert Research and Technology Studies) simulates the operations of planetary exploration, exposing astronauts to the technologies and techniques that will protect them against the extreme environment of Mars or the Moon.

Desert RATS also looks at the possibility of humans one day occupying planets, moons and near-Earth asteroids. Habitats are trialled – the most recent being the HDU-DSH (Habitat Demonstration Unit – Deep Space Habitat) – that allow for crews to set up a longer-term base. Experiments are performed on these living and working quarters to ensure astronauts are comfortable, safe and able to carry out tasks while communicating with Earth-based crews.

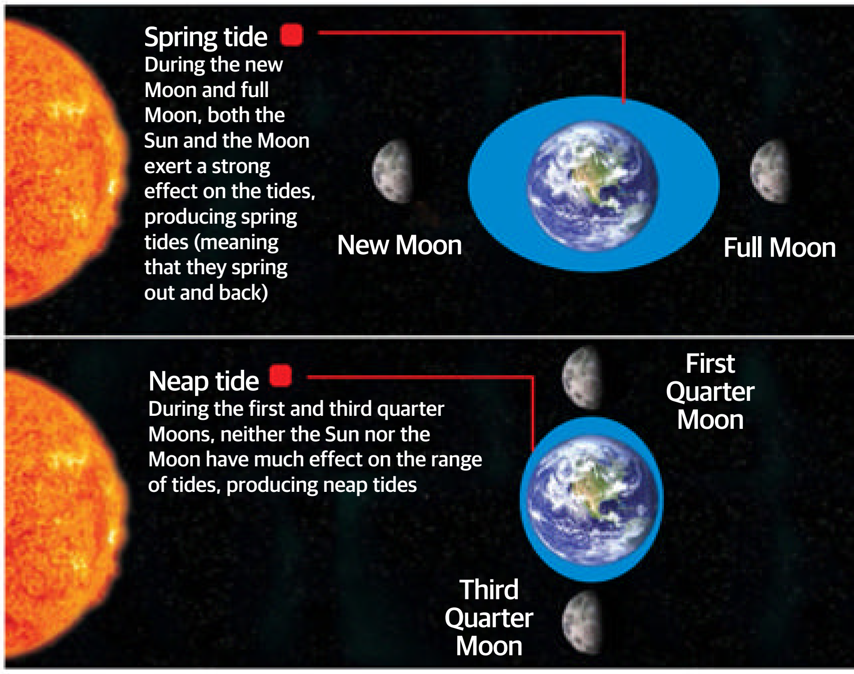
Without the benefit of these kinds of analog missions – the likes of which have been conducted since the days of Apollo – space flight and exploration would be almost impossible. With them, astronauts, engineers and scientists are gaining new understanding, advancing science and coming up with new methods and technology. The future of human space exploration continues to look bright. ■

All About... THE MOON

The Moon is the Earth's only natural satellite, and the only celestial body that we've set foot on other than our own planet. But even though we know more about it than any other celestial body, the Moon continues to fascinate

The Moon and tides

Along with the Sun, the Moon exerts serious force on the Earth's tides. Whether the tides vary widely or not much at all has a lot to do with the interactions between the solar and lunar cycles. When they are together, their combined effects produce tidal variations called spring tides – high tides are very high and low tides are very low. If the Sun and Moon are on the opposite sides of the sky, they nullify each others' effects, producing neap tides – with little variation.



Because we can easily discern features on the Moon with the naked eye, it has been a sense of wonder to us since ancient times. The Moon is the brightest object in our sky after the Sun, and influences everything from our oceans to our calendars. It's always been 'the Moon' because we didn't know that there were any others. Once Galileo discovered in 1610 that Jupiter had satellites, we've used the word 'moon' to describe celestial bodies that orbit larger bodies, which orbit stars. Since the Moon has always been so present, it might not seem worth studying. Yet there's a reason why we continue to return to it – we still have plenty to learn from our satellite.

The Moon is the fifth-largest and second-densest satellite in the Solar System. Its diameter is 27 per cent of Earth's at 3,476 kilometres (2,160 miles), while its mean density is 60 per cent that of the Earth's. This makes the Moon the largest satellite in size relative to the planet that it orbits. The Moon is also unusual because its orbit is more closely aligned to the plane of the ecliptic – the plane in which the Earth orbits. Most planetary satellites orbit closer to their planet's equatorial plane, but the Moon is inclined from the plane of the ecliptic by approximately 5.1 degrees.

Its average distance from the Earth is 384,400 kilometres (239,000 miles), and it completes an orbit once every 27.3 days. The Moon is in synchronous rotation with the Earth – its rotation and orbital period are the same – so the same side is almost always facing our planet. This is called the 'near side' of the Moon, while the opposite side is the 'far' or 'dark' side (although it gets illuminated just as often as the near side). This hasn't always been the case; the Moon used to rotate faster, but the influence of the Earth caused it to slow and become locked.

Although we say that we can only see one side of the Moon at a time, that's not strictly true. The Moon's orbit isn't quite circular – it has an eccentricity of 0.0549. The Moon also wobbles a bit along its orbit. These two factors cause some variations in how much of the Moon that we see, called librations. When the Moon is closest to the Earth, called the perigee, it orbits slightly slower than it rotates. This means that we can actually get a glimpse of about eight degrees of longitude of its eastern far side. When the Moon is at its furthest point away in its orbit, the apogee, its orbit is slightly faster than its rotation. So we get a glimpse of eight degrees of longitude on its western far side. This is called longitudinal libration.

The Moon also appears to rotate towards and away from the Earth. This is due to the 5.1-degree inclination of its orbit, as well as the 1.5-degree tilt of the Moon's equator to the plane of the ecliptic. This results in us seeing about 6.5 degrees of latitude on the far side along both the sides of the poles. The Moon's orbit also means that it appears to move about 13 degrees across the sky each day, and this movement accounts for the lunar phases.

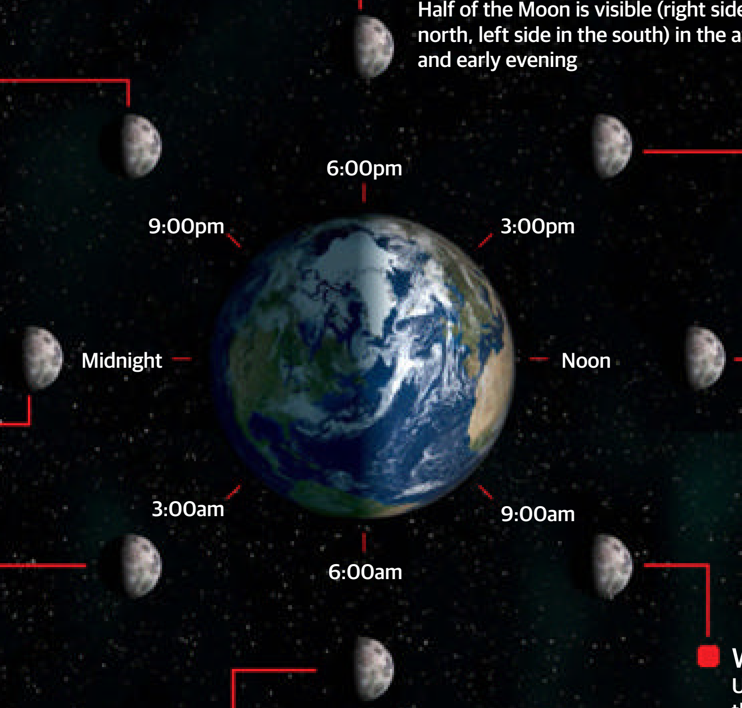
> "The Moon is the fifth-largest and second-densest satellite in the Solar System. Its diameter is 27% of Earth's"

The Moon's gravitational pull has a strong effect on the Earth. The most obvious effect to us is the tides. High tide occurs when the level of water at the coastline rises, and low tide occurs when the water rushes further out. While some coastlines experience one high tide and one low tide per day, of equal strength, others have different strengths, timing and numbers of tides. Measuring and predicting these tides is incredibly important for everything from fishing to navigating intercoastal waterways. We use the term 'tides' to describe oceanic tides, but tides also occur on a smaller level in lakes as well as the Earth's atmosphere and crust.

Scientists believe that the Moon formed when a huge celestial body about the size of Mars (which has been given the name Theia) impacted with a young Earth. This is known as the giant impact hypothesis. This force sent debris out into Earth's orbit, which fused to form the Moon. However, in 2012, an analysis of rock samples taken from the Moon during the Apollo missions showed that the Moon's composition is almost identical to Earth's. This calls the giant impact hypothesis into question, because previously we thought that at least some of the Moon's material had to have come from Theia.

How the moons measure up

The Moon's orbit



Waxing gibbous
Between 51 and 99 per cent of the Moon is visible (right side in the north, left side in the south) in the later afternoon and most of the evening

First quarter
Half of the Moon is visible (right side in the north, left side in the south) in the afternoon and early evening

Waxing crescent
Up to 49 per cent of the Moon is visible (right side in the northern hemisphere, left side in the southern hemisphere) in the afternoon and after dusk

Full Moon
The entire Moon is visible all night long

New Moon
The first visible crescent in the southern hemisphere, seen after sunset

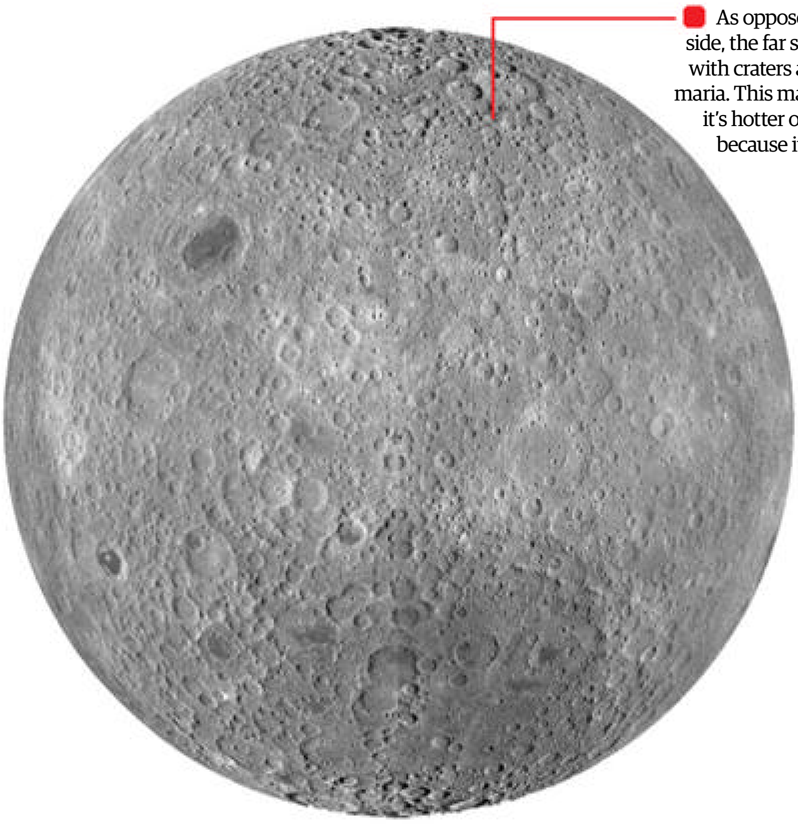
Waning gibbous
Between 51 and 99 per cent of the Moon is visible (left side in the north, right side in the south) for most of the evening and in the early morning

Third quarter
Half of the Moon is visible (left side in the north, right side in the south) in the late evening and morning

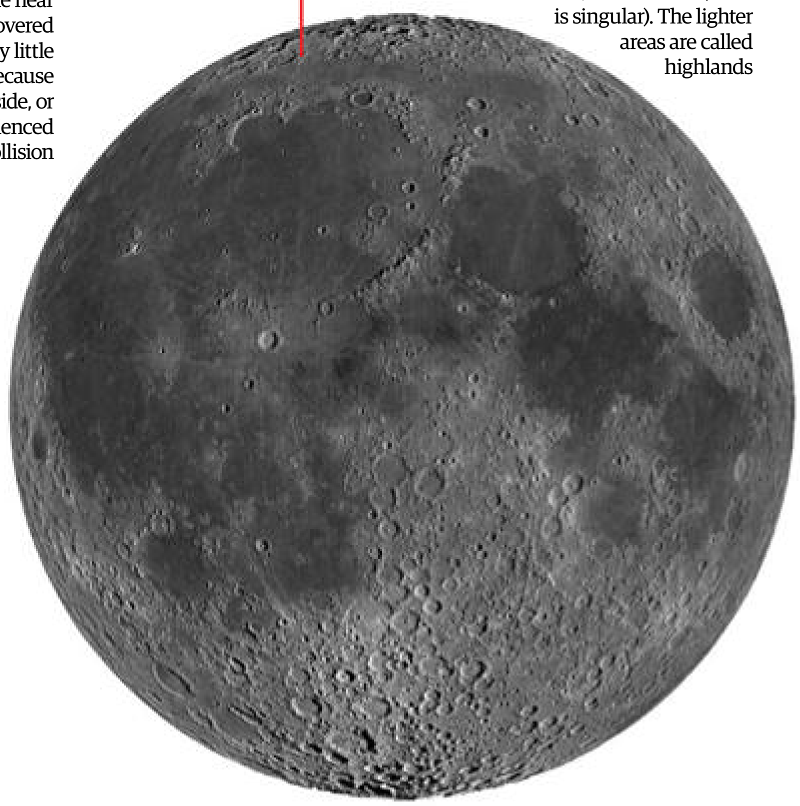
Waning crescent
Up to 49 per cent of the Moon is visible (left side in the north, right side in the south) just before dawn and in the morning

Two sides of the Moon

As opposed to the near side, the far side is covered with craters and very little maria. This may be because it's hotter on that side, or because it experienced a collision



The near side of the Moon is mostly covered in dark areas that were originally thought to be seas, called maria (mare is singular). The lighter areas are called highlands



The Moon inside and out

The Earth's only known satellite shares some remarkable similarities with our home planet

Although the Moon may seem like a solid rock, it's actually differentiated like the Earth; it has a core, a mantle and a crust. The Moon's structure likely came from the fractional crystallisation of a magma ocean that once covered the Moon. This probably happened not long after the Moon was formed, about 4.5 billion years ago. This means that as the magma ocean cooled, its composition changed as the different minerals within the melt crystallised into solids. The denser materials sank, forming the mantle, while less dense materials floated on top and formed the crust.

We believe that the core is probably very small, with a radius about 20 per cent the total size of the Moon. By contrast, most differentiated celestial bodies have cores about 50 per cent of their total size. The core itself comprises a solid innermost core that is rich in iron as well as nickel and sulphur, with a radius of 240 kilometres (150 miles). This is surrounded by a fluid outer core, with about a 300-kilometre (186-mile) radius. Between the core and the mantle, there's a boundary layer of partially melted iron that has about a 500-kilometre (300-mile) radius. It is also known as the lower mantle. The upper mantle is mafic - rich in magnesium and iron, topped by a crust of igneous rock called anorthosite. It mainly includes the elements aluminium, calcium iron, magnesium and oxygen, with traces of other minerals. We estimate the crust to be around 50 kilometres (31 miles) thick.

The Moon has no plate tectonics, but it does have seismic activity. When astronauts with the Apollo programme visited the Moon, they discovered that there are moonquakes - the Moon's equivalent of earthquakes. Moonquakes aren't nearly as strong as earthquakes, but they can last longer because there's no water to lessen the effects of the vibrations.

"The Apollo astronauts discovered seismic activity on the Moon"

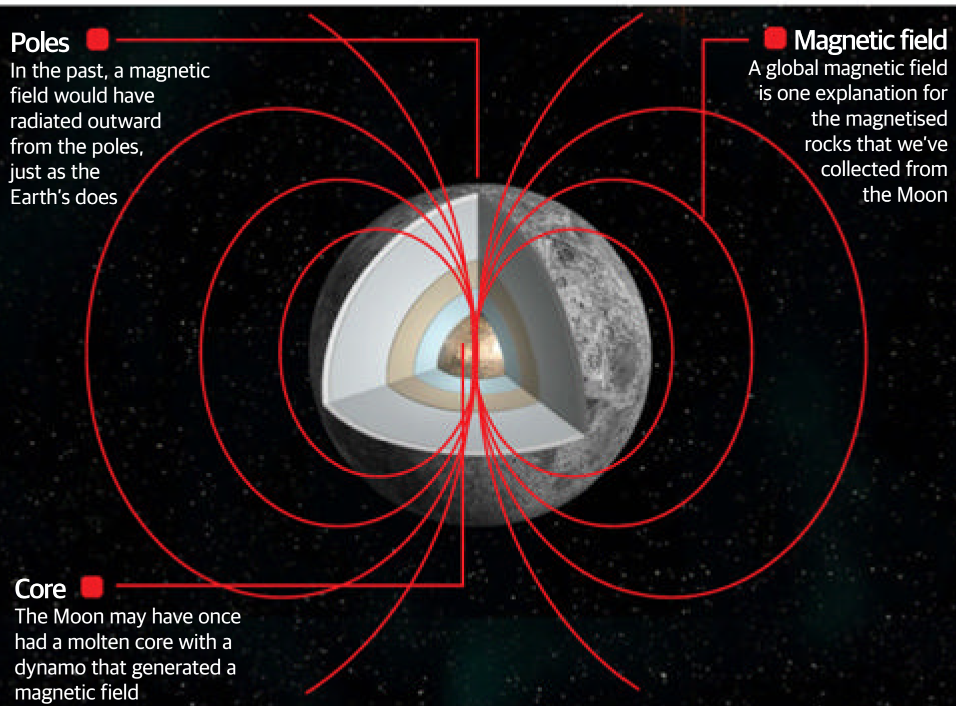
Seismometers placed by Apollo astronauts showed that the strongest moonquakes are about 5.5 on the Richter scale. There are four different types of moonquakes: shallow, deep, thermal and meteorite. Shallow ones occur just 20 kilometres (12 miles) below the surface, while deep moonquakes can be as deep as 700 kilometres (435 miles). These deep moonquakes are probably related to stresses on the Moon caused by its eccentric orbit and gravitational interactions between it and the Earth. Thermal earthquakes occur when the crust of the Moon heats and expands. This happens when the Moon is bathed in sunlight again after its two-week-long night. Finally, meteorites hitting the Moon can also cause a type of moonquake. However, shallow moonquakes are the strongest and most common. Nearly 30 of them were recorded between 1972 and 1977 by seismometers (turned off in 1977) that were left on the Moon's surface. This seismic data has helped us to determine the Moon's internal composition.

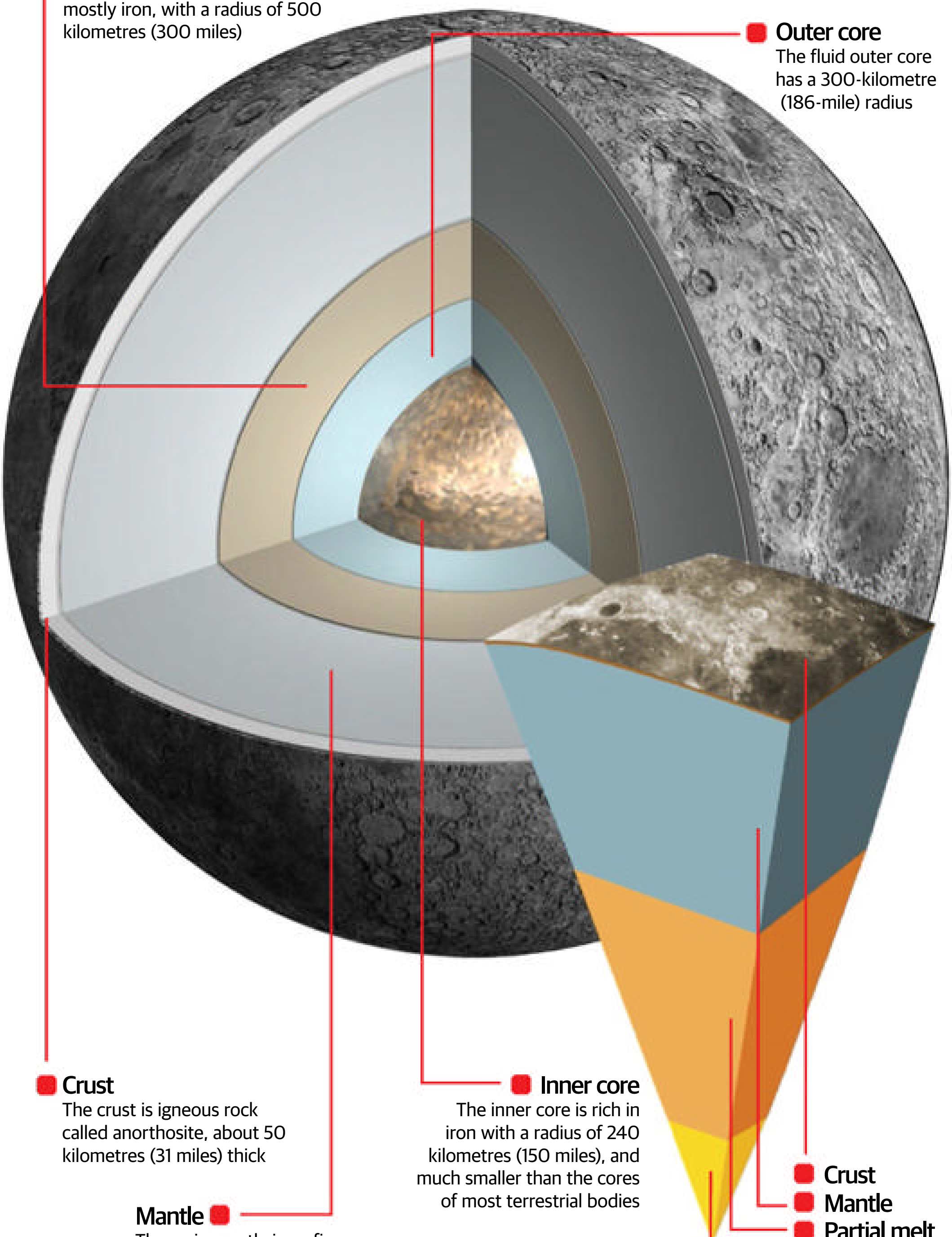
The dominating feature on the near side of the Moon's surface, called maria, are the result of ancient volcanic activity. These vast, dark plains are basalts - igneous rock that formed after lava erupted due to partial melting within the mantle. These basalts show that the Moon's mantle is much higher in iron than the Earth's, and has a varied composition. Some basalts are very high in titanium, while others are higher in minerals like olivine. For the most part, they flowed into impact basins.

These basalt maria have influenced the Moon's gravitational field because they're so rich in iron. The gravitational field contains mascons, big positive gravitational anomalies that influence how spacecraft orbit the Moon. They're also a bit of a mystery, however; the maria can't explain all of the mascons that have been tracked by the Doppler effect on the radio signals emitted by spacecraft that orbit the Moon. And there are also some large maria without associated mascons.

The magnetic field mystery

The Moon does have an external magnetic field - it's weak, less than one-hundredth that of the Earth's magnetic field. It's not a dipolar magnetic field like the Earth, which has a field that radiates outward from the north and south poles. So where did this magnetism come from? Researchers believe that the Moon once did have a dipole magnetic field, created by a dynamo - a convecting liquid core of molten metal. But we aren't sure what powered that dynamo. It could have worked like the Earth's dynamo. The Earth's dynamo powers itself, as elemental radioactive decay maintains convection in the core of our planet. The Moon could also have had a dynamo powered by the cooling of elements at the core. Yet if this were true, the magnetic field would have been completely gone about 4 billion years ago because the core is so small. Yet we have discovered magnetised lunar rocks that are younger than this. Another theory is that the Moon's dynamo was powered by the pull of the Earth's gravity when they were much closer together, or that impacts from large asteroids generated the magnetic field.





How the Moon formed

The Moon in numbers

Fascinating facts and figures about Earth's only satellite

400

How many times bigger the Sun is than the Moon. But it's also about 400 times further away from the Earth, which is why they look the same size in the sky

29.5 days

The length of a lunar month. It's longer than the amount of time it takes the Moon to orbit the Earth because the Earth is moving too

12

The number of people who have actually set foot on the Moon

3.8cm (1.5in)

The distance the Moon is moving away from the Earth each year

13 hours

The amount of time it takes to reach the Moon by rocket

16.6kg (36.5lb)

The amount you would weigh on the Moon if you weighed 100kg (220lb) on the Earth

On the surface

The surface of the Moon is about contrasts: light and dark, hot and cold

The landscape of the Moon is dominated by three main features: maria, terrae and craters. The basalt maria appear dark due to their high iron content and are much more prevalent on the near side of the Moon. Other volcanic features located on the surface of the Moon include domes and rilles. Domes are shield volcanoes that are round and wide with gentle slopes, while rilles are twisting sinuous formations caused by channels of flowing lava.

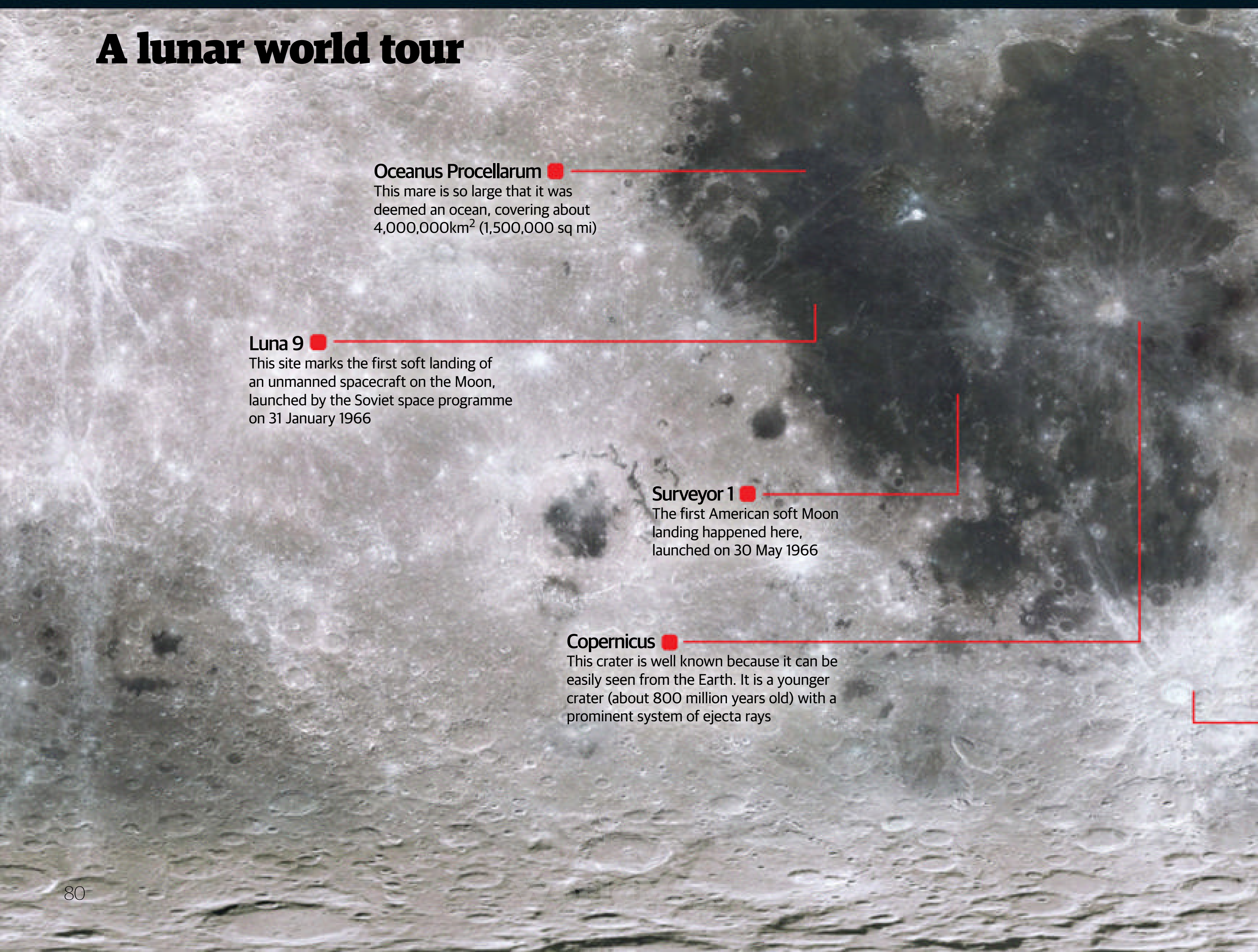
The lighter areas on the Moon are called terrae (terra is singular), or lunar highlands. They are made up of anorthosite, the type of igneous rock that dominates the overall crust of the Moon. While this type of rock can be located in some places on Earth, it's not generally found on the surface due to plate tectonics and deposits. These highlands reflect light from the Sun and make it appear that the Moon is glowing at night.

Both the maria and terrae have impact craters which were formed when asteroids and comets struck the surface of the Moon. These craters range in size from very tiny to massive. It is estimated that there are around 300,000 craters on the near side of the Moon that are wider than one kilometre (0.62 miles). The largest impact crater, called the South Pole-Aitken Basin, is about 2,500 kilometres (1,550 miles) in diameter and 13 kilometres (eight miles) deep. The biggest craters also tend to be the oldest, and many are covered in smaller craters. Younger craters have more sharply defined edges, while older ones are often softer and rounder. If the impact was especially large, material may be ejected from the surface to form secondary craters.

In some cases, the basalt eruptions flowed into or over large impact craters called basins. In general, the terrae have far more craters, because the maria are younger in age than the terrae. While the Moon isn't much younger than the Earth, the Earth has processes that continue to change its surface over time, like erosion and plate tectonics. The Moon doesn't experience these, which is why some impact craters are up to 500 million years older than the basalt filling them.

The loose soil on the Moon is called regolith. It's powdery and filled with small rocks. Over time,

A lunar world tour

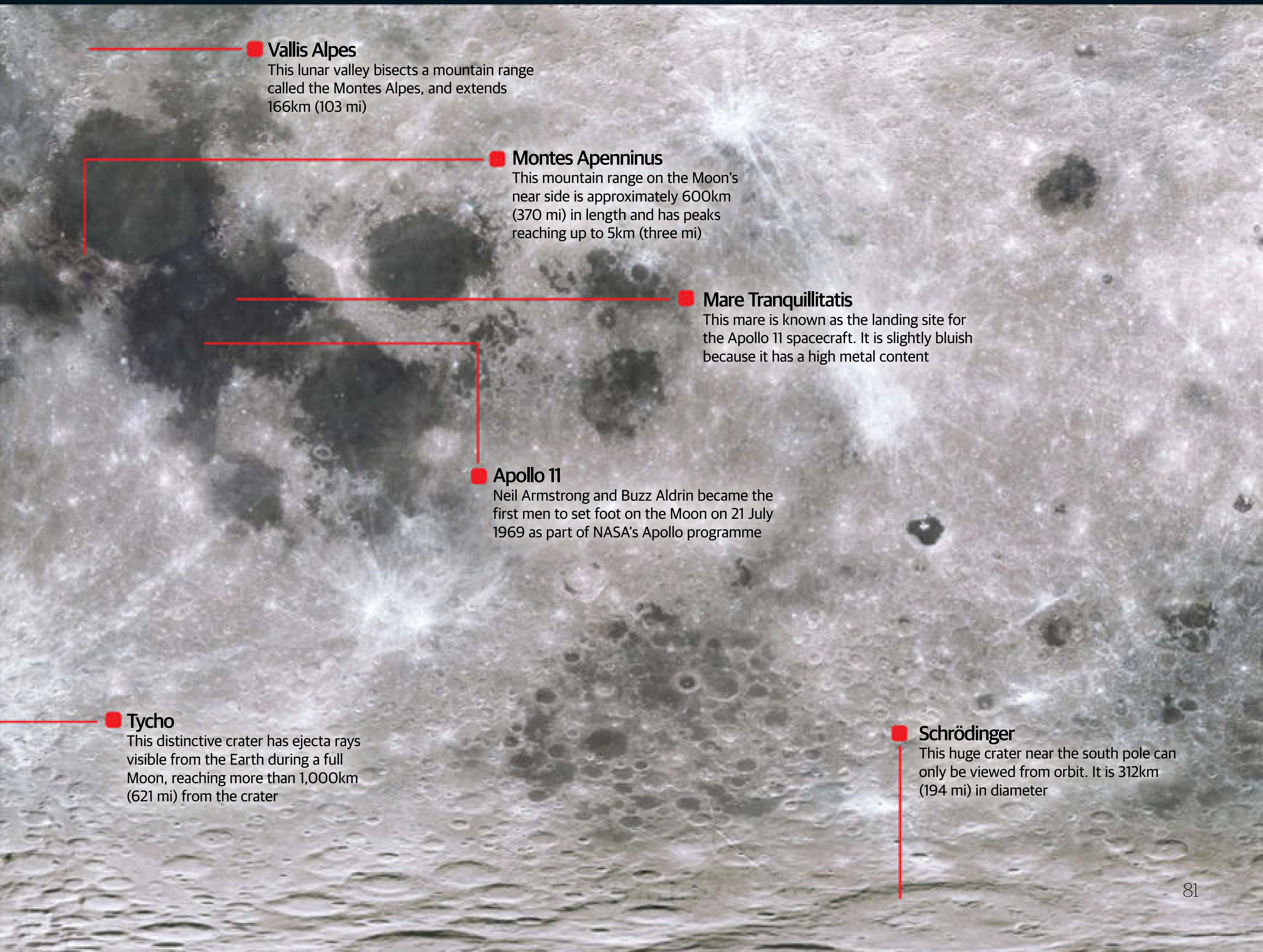


impacts from meteors, as well as space weathering (solar wind, cosmic rays, meteorite bombardment and other processes), break down the rocks and grind them into dust. Aside from the basalt and anorthosite rocks, there are also impact breccias - rock fragments that were welded together by meteor impacts - and glass globules from volcanic activity.

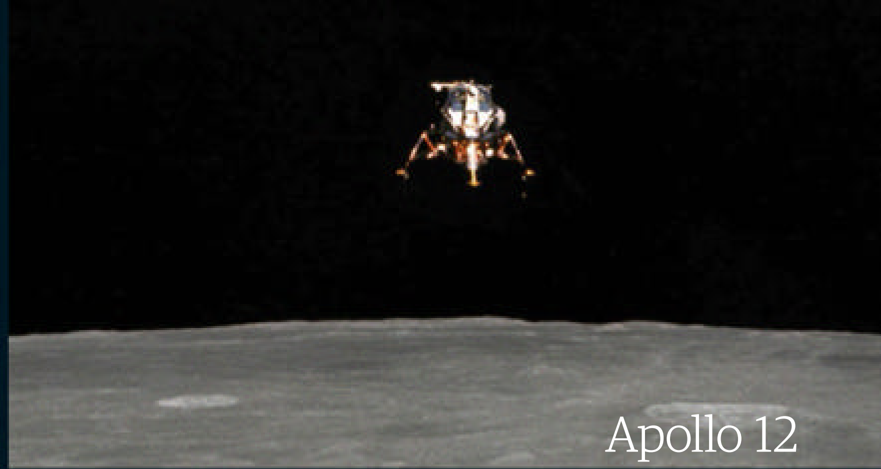
Although you may see the term 'lunar atmosphere' used in some places, the Moon is actually considered to exist in a vacuum. There are particles suspended above the surface, but the density of the Moon's atmosphere is less than one hundred trillionth that of the Earth's atmosphere. What little atmosphere there is gets quickly lost to outer space, and is constantly replenished. Two processes help to replenish the Moon's atmosphere: sputtering and outgassing. Sputtering occurs when sunlight, solar wind and meteors bombard the surface and eject particles. Outgassing comes from the radioactive decay of minerals in the crust and mantles, which can release gases like radon.

The Moon has a very minor axial tilt, so there aren't seasons in the same way that we have them here on Earth. However, temperatures on the Moon can change dramatically because there's no atmosphere to trap heat, and portions of the Moon may be either in full sunlight or total darkness depending on where it is in its rotation. Full sunlight can mean temperatures of greater than 100 degrees Celsius (212 degrees Fahrenheit). But at the end of the lunar day, the temperature can drop by hundreds of degrees. There are also big differences in temperatures depending on the surface features. For example, the Moon is coldest in its deepest craters, which always remain in darkness. The coldest temperature ever recorded in the Solar System by a spacecraft was measured by the Lunar Reconnaissance Orbiter in the Hermite Crater near the Moon's north pole at -248 degrees Celsius (-414 degrees Fahrenheit).

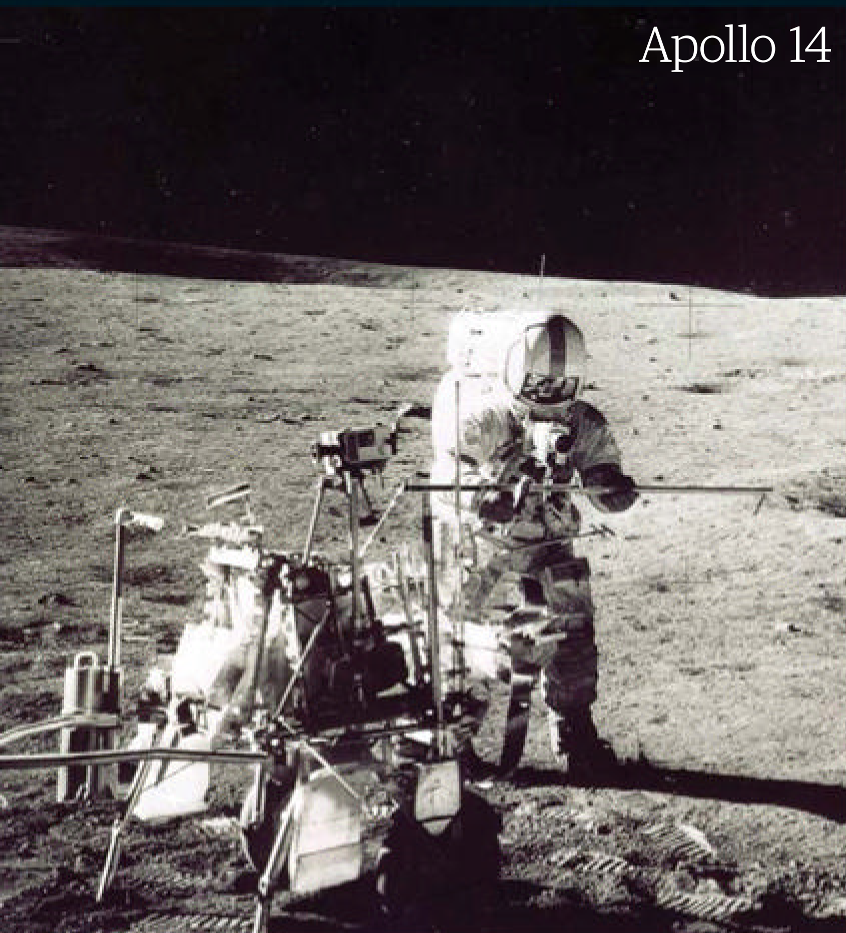

This rover travelled across the Moon's surface as part of the Apollo 17 mission in 1972




Apollo 11


Apollo 12

Exploring the Moon: the past


Apollo 14

Apollo 11 21 July 1969
NASA astronauts Buzz Aldrin and Neil Armstrong became the first humans to set foot on another body in space when they landed on the Moon in 1969. This mission ended the race to the Moon between the United States and the USSR.

Apollo 12 19 November 1969
The second spacecraft to land on the Moon, Apollo 12 used a Doppler effect radar technique to precisely land the spacecraft within walking distance of the Surveyor 3 probe, which had landed on the lunar surface about two years prior.

Apollo 14 5 February 1971
The commander on board the third spacecraft to land on the Moon was Alan Shepard, who, a decade earlier on 5 May 1961, had become the second person in space after Yuri Gagarin and the first American as part of the Mercury programme.

Apollo 15 30 July 1971
NASA deemed this Moon landing the most successful so far out of its manned missions. It is also known as the first of the longer missions to the Moon, called 'J missions', staying for three days.

Apollo 16 21 April 1972
Apollo 16 became the first spacecraft to land in the highlands on the Moon, which let them gather older lunar rocks. The astronauts also spent about three days on the surface.

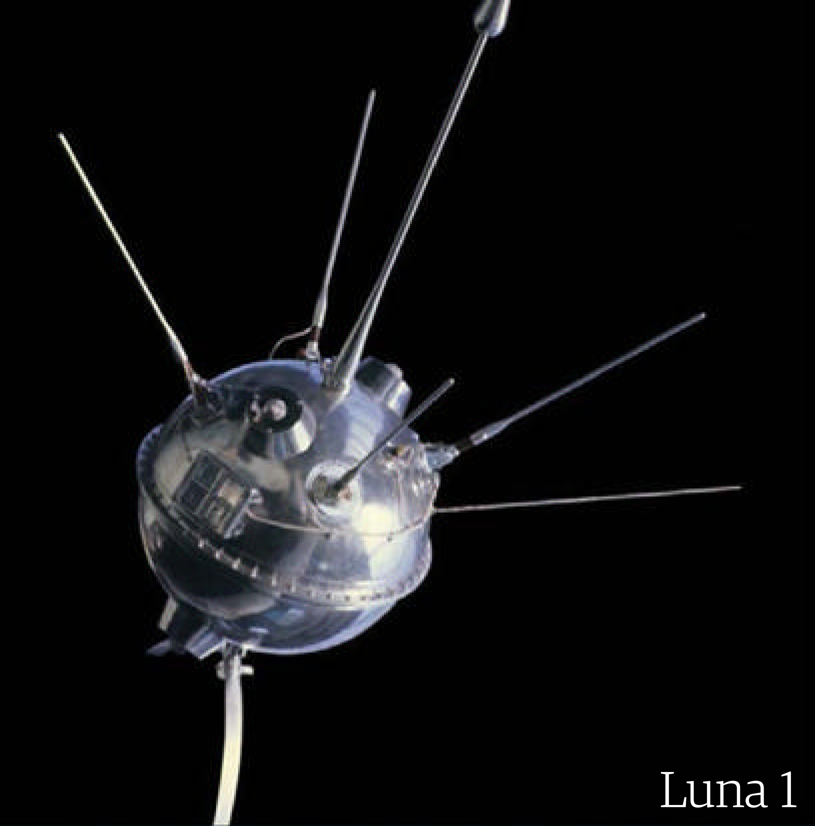
Apollo 17 11 December 1972
This last manned mission to the Moon was the only one to carry the Traverse Gravimeter Experiment (TGE) that measured relative gravity at different sites on the Moon.

Luna 1 4 January 1959
This Soviet probe was the first to reach the vicinity of the Moon and the first to break out of geocentric orbit, however, it did not actually impact the Moon as had originally been planned.

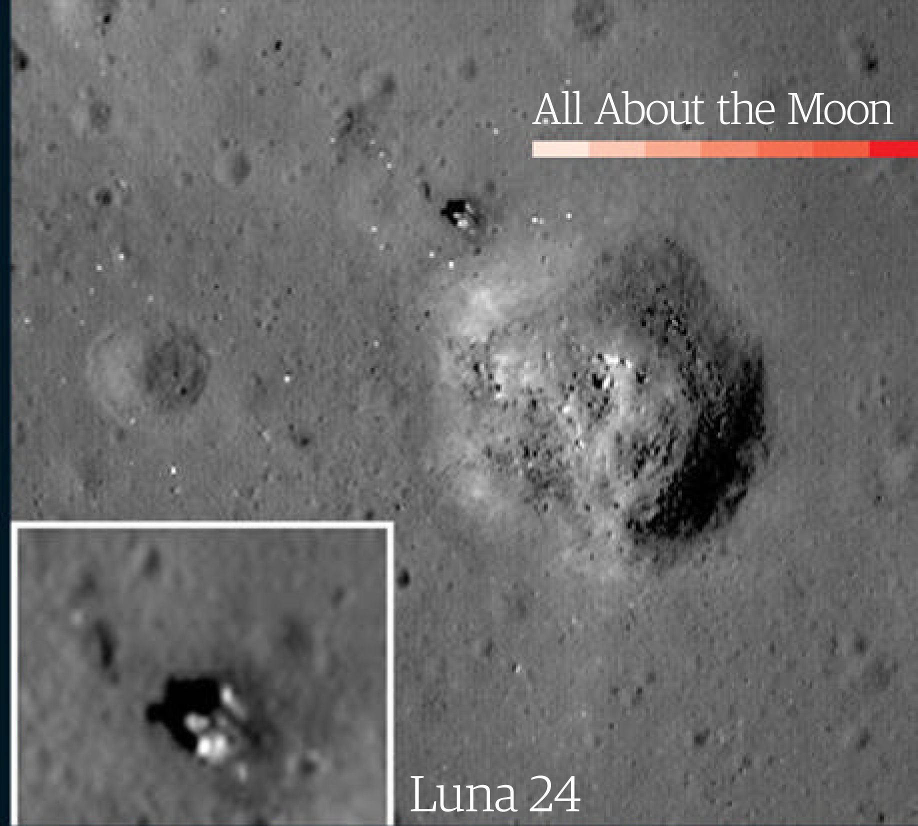
Luna 21 15 January 1973
This Soviet spacecraft landed on the Moon and carried a lunar rover, Lunokhod 2. It performed numerous experiments and sent back more than 80,000 images before failing.

Luna 24 22 August 1976
This was the last of the Luna missions, successfully landing near Mare Crisium to recover samples. It remains the last spacecraft to have a soft landing on the Moon's surface.

Apollo 15

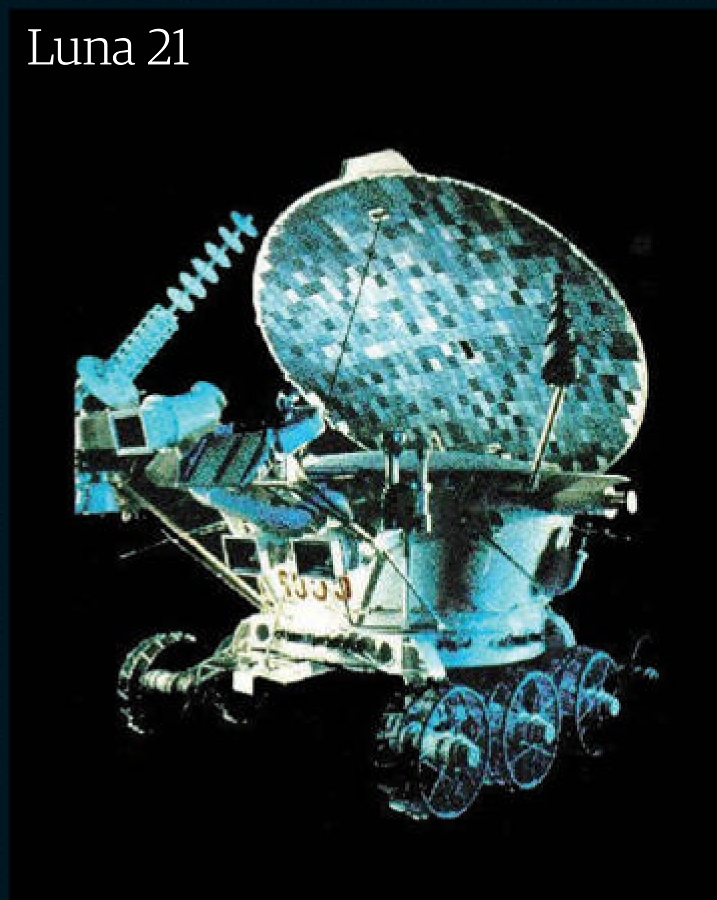


Luna 1

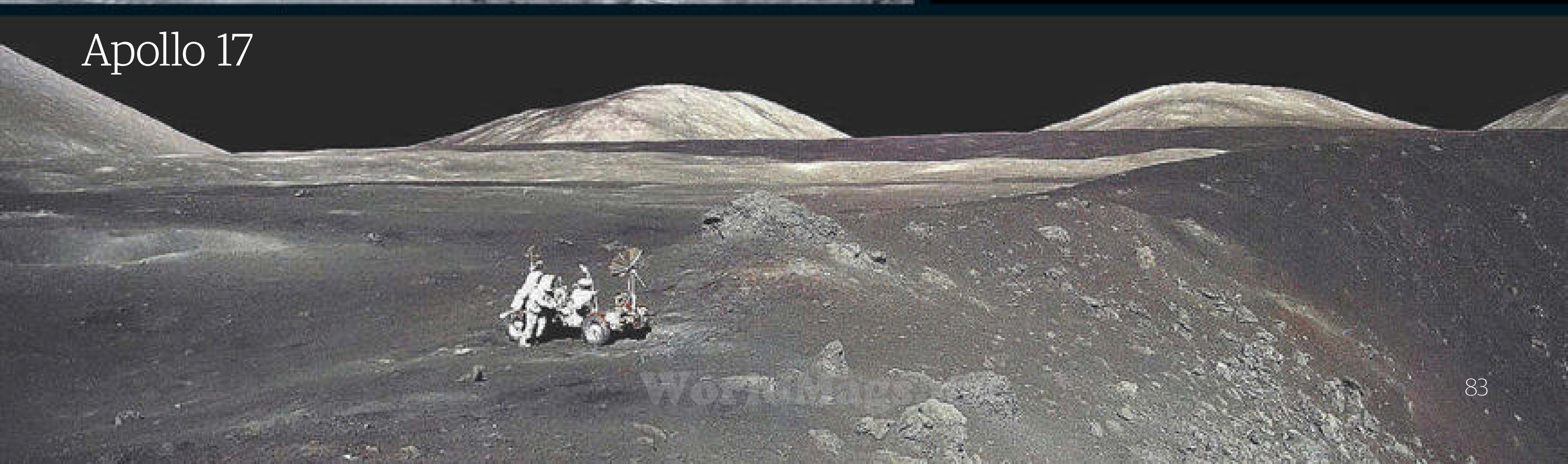


Luna 24

Apollo 16



Luna 21



Apollo 17

Exploring the Moon: present and future

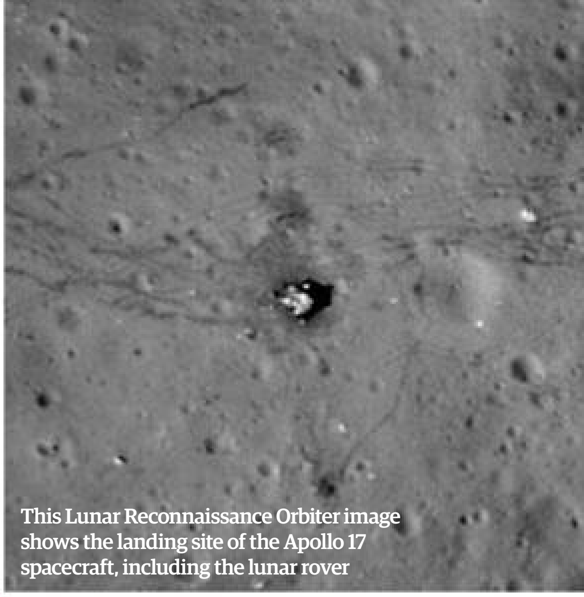
We've been studying the Moon for over 50 years, and thanks to a host of pioneering missions we now know more about our satellite than ever before

Although there hasn't been a manned mission to the Moon since 1972 and there were no soft landings at all until 1966, we're still exploring our satellite. Currently the Lunar Reconnaissance Orbiter (LRO) is still circling the Moon. It launched on 18 June 2009, and became the first NASA mission to the Moon in more than a decade. The LRO is meant to be a precursor to future manned missions, and was originally designed to spend just a year in orbit. However, the mission was extended several times. It was designed to extensively map the Moon in high resolution, explore the potential of ice in the polar regions, study the deep space radiation, and continue to map the surface of the Moon. The other current NASA mission is ARTEMIS, an extension of an earlier satellite mission. Two small probes have been orbiting the Moon together since summer 2011, having previously performed lunar and Earth flybys.

The Lunar Crater Observation and Sensing Satellite (LCROSS) was launched along with the LRO and considered an inexpensive way to look for water ice, and it was successful. The LCROSS discovered ice in the Cabeus crater near the Moon's south pole after its upper stage impacted as planned on 9 October 2009. Two small spacecraft under the name GRAIL A and GRAIL B were launched on 10 September 2011 and impacted on 17 December 2012, having collected data to help understand how terrestrial planets have evolved. Japan, India and China have all had lunar probes in the last six years as well. Currently there are several proposed lunar missions on the table for launch within the next few years, coming from the United States, China, Russia and India.

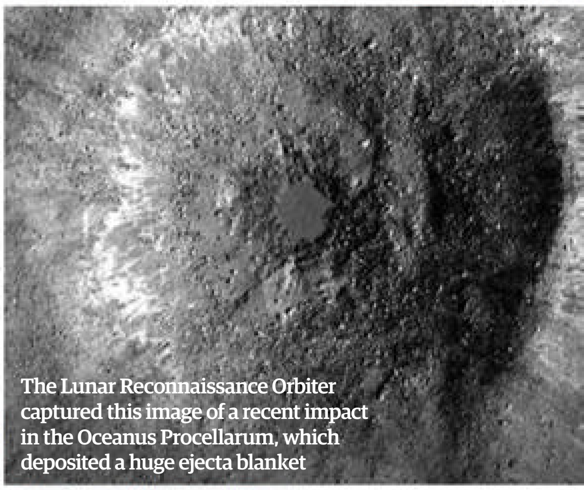
The image taken by the Lunar Reconnaissance Orbiter shows the Apollo 11 landing site, including the astronauts' footsteps, landing module and discarded tools

"It was designed to extensively map the Moon in high resolution"



This Lunar Reconnaissance Orbiter image shows the landing site of the Apollo 17 spacecraft, including the lunar rover

Buzz Aldrin and Neil Armstrong became the first humans to walk on the Moon in 1969



The Lunar Reconnaissance Orbiter captured this image of a recent impact in the Oceanus Procellarum, which deposited a huge ejecta blanket

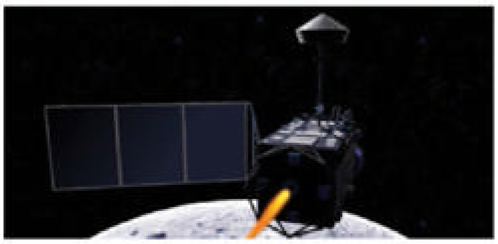
Current and future missions

Luna-Glob
Russia

This Russian Federal Space Agency programme is scheduled to be the first of a series of missions, with the ultimate goal of creating a robotic base on the Moon. Its goals include gathering seismic activity, studying cosmic rays, and studying the origin of the Moon.

Chang'e 2
China

This Chinese probe was launched on 1 October 2010 and left lunar orbit in November to go on an extended mission. Chang'e 2 was designed to study future landing sites.



Kaguya
Japan

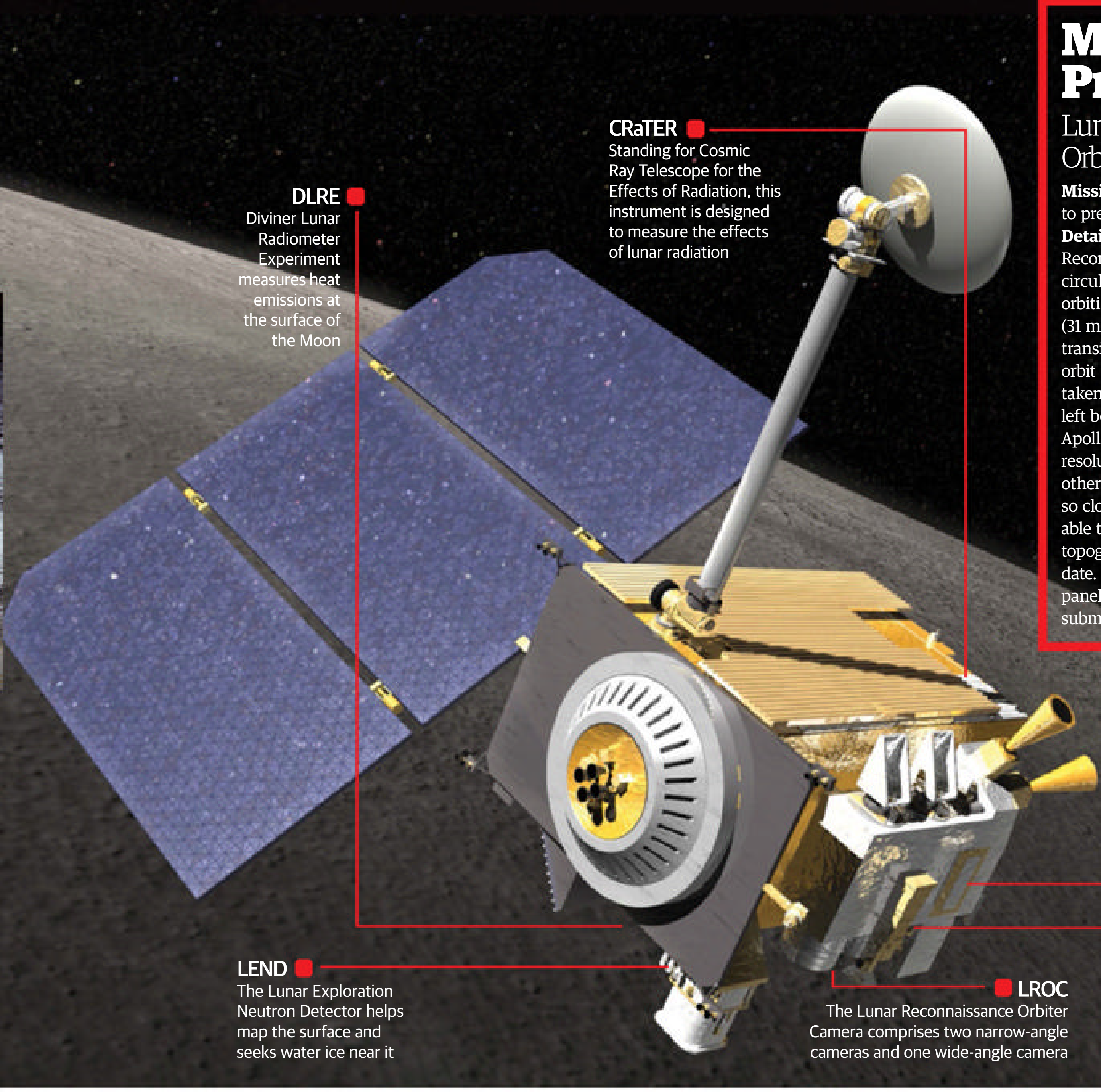
Also known as SELENE, this Japanese orbiter was launched on 14 September 2007 and circled the Moon before impacting on 10 June 2009. Kaguya measured the Moon's gravity, studied the surface and sought information on the Moon's history.

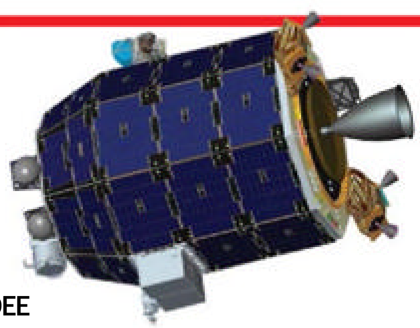
Mission Profile

Lunar Reconnaissance Orbiter

Mission dates: 18 June 2009 to present

Details: Currently the Lunar Reconnaissance Orbiter is in a circular orbit around the Moon, orbiting at about 50 kilometres (31 miles) before eventually transitioning to a more elliptical orbit (which will save fuel). It has taken the first images of equipment left behind on the Moon by the Apollo missions, providing high-resolution shots of lunar rovers and other equipment. As the LRO is so close to the surface, it has been able to provide the most accurate topographic map of the Moon to date. It also carries a microchip panel containing 1.6 million names, submitted by the public.





LADEE
USA

NASA plans to launch the Lunar Atmosphere and Dust Environment Explorer (LADEE) in August 2013. It hopes to learn more about the lunar atmosphere before there are more manned missions, including the dust on the Moon's surface.

© Lunar Missions Ltd

Lunar Mission One
UK

This UK-led mission – funded by private donations – hopes to survey the South Pole of the moon, an area that's previously remained unexplored. With an aim to drill down at least ten metres, but possibly 100, they hope to learn more about Earth's satellite.

Chandrayaan-1
India

This was India's very first unmanned space probe. It launched on 22 October 2008 and the mission ended on 29 August 2009. It launched an impact probe that planted an Indian flag on the south pole, making it the fourth country to place a flag on the Moon.

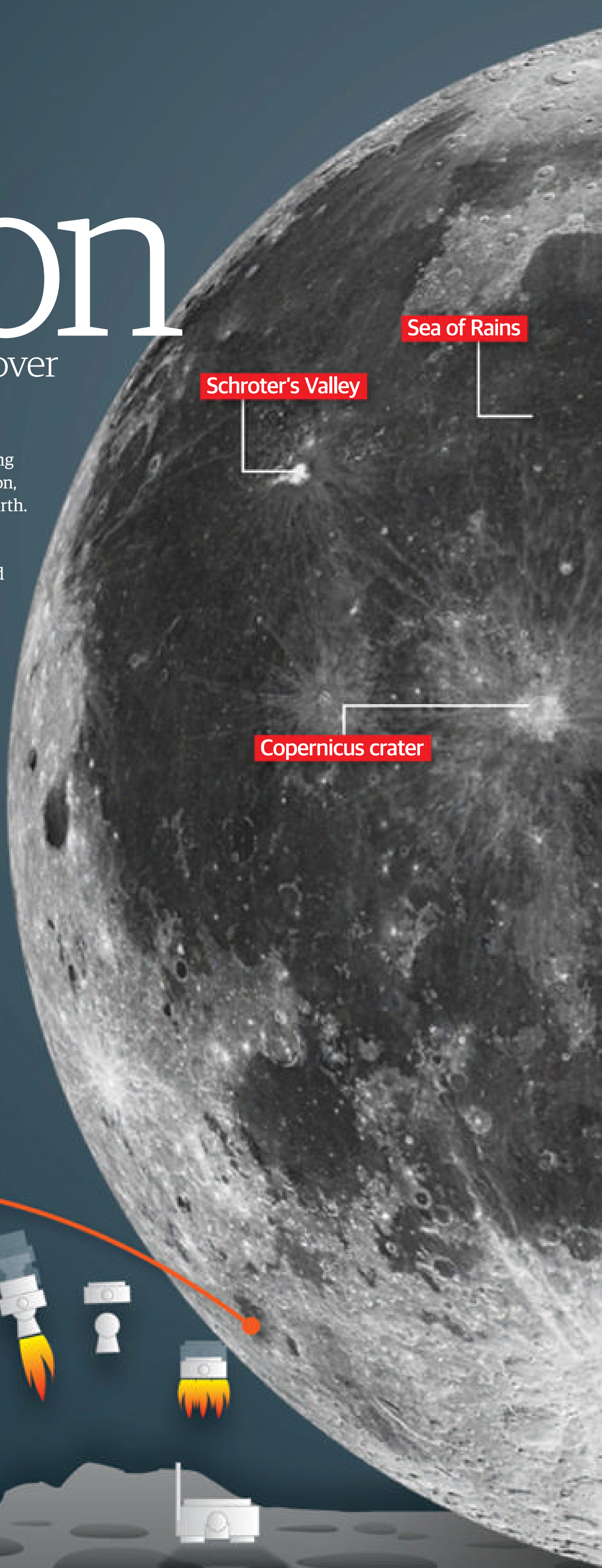
Explore... The Moon

Take a tour of our nearest neighbour and discover a world much stranger than you thought

The Moon's diameter is 27 per cent of Earth's, which is freakishly large. Jupiter's moon Ganymede is larger in absolute terms, but compared to its parent planet it is just a speck, with less than a fiftieth of the diameter. The disproportionate size of the Moon reflects its unusual origins. Most other moons are captured asteroids, or leftover material from the ball of dust and gas that coalesced to form the Solar System. But the Moon is made from the rubble of another planet, called Theia, that collided with Earth around 4.5 billion years ago.

When it was first formed, the Moon may have been ten times closer to Earth than it is today and would have caused tides on Earth several kilometres high. Over billions of years, the gravitational drag of the tides has slowed the Moon's orbit, causing it to spiral outwards from us. Earth's gravity also raises small 'land tides' on the Moon, stretching it slightly and creating another drag that has synchronised its rotation, so that it always presents the same face to Earth.

The full Moon in the night sky looks flat, rather than darkening at the edges as you'd expect from a 3D sphere. This effect is caused by the unusual properties of the lunar soil, or 'regolith', which reflects more light when the Sun shines at a low angle, than when it is directly overhead. Moon rock is about the colour of a dry road, but a full Moon appears much brighter than that, because all the tiny shadows cast by the regolith disappear when the Sun shines from behind our viewpoint. The regolith can be up to 20 metres (66 feet) deep on the Moon's highlands and in the early days of lunar exploration there were real concerns that spacecraft would simply sink into it.



How to get there

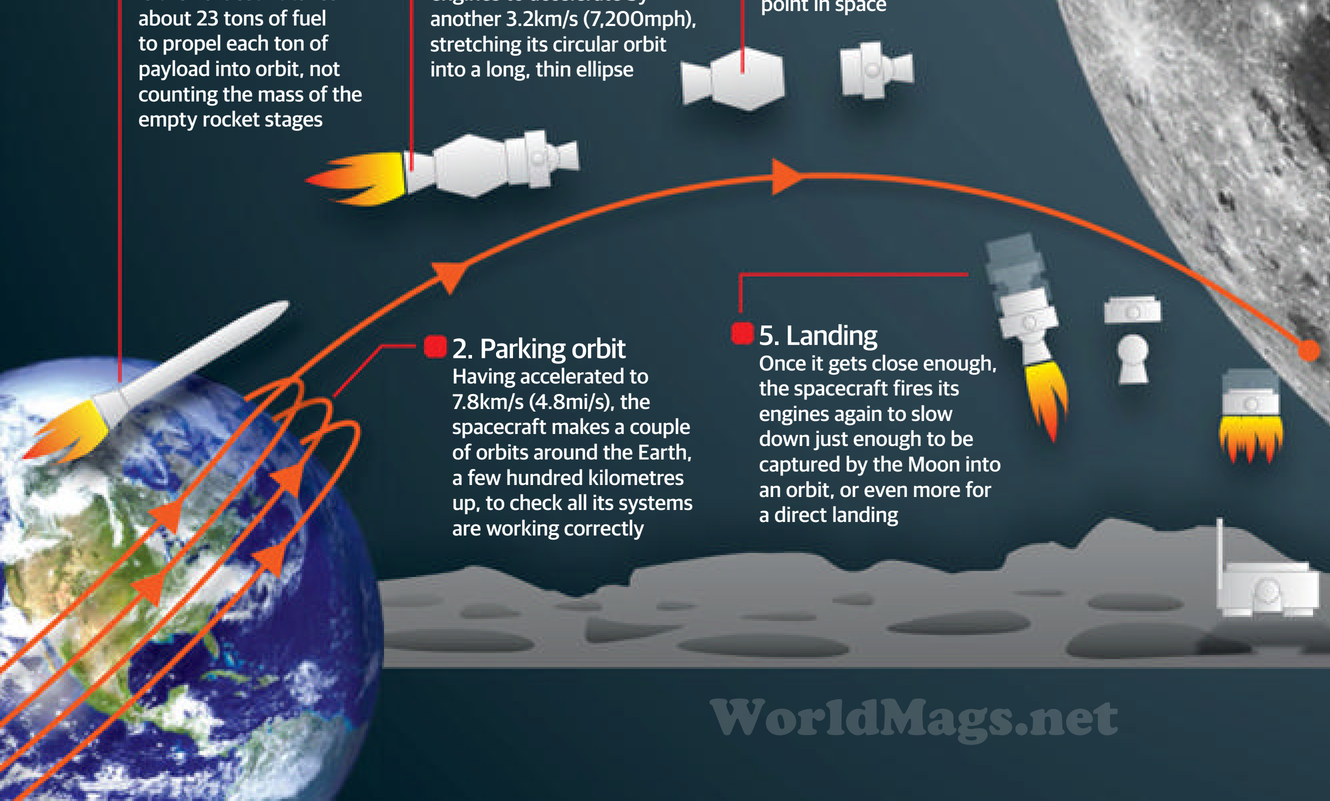
1. Lift off
The first 200km (124mi) is the hardest. It takes about 23 tons of fuel to propel each ton of payload into orbit, not counting the mass of the empty rocket stages

2. Parking orbit
Having accelerated to 7.8km/s (4.8mi/s), the spacecraft makes a couple of orbits around the Earth, a few hundred kilometres up, to check all its systems are working correctly

3. Transfer burn
To reach the Moon, the spacecraft must fire its engines to accelerate by another 3.2km/s (7,200mph), stretching its circular orbit into a long, thin ellipse

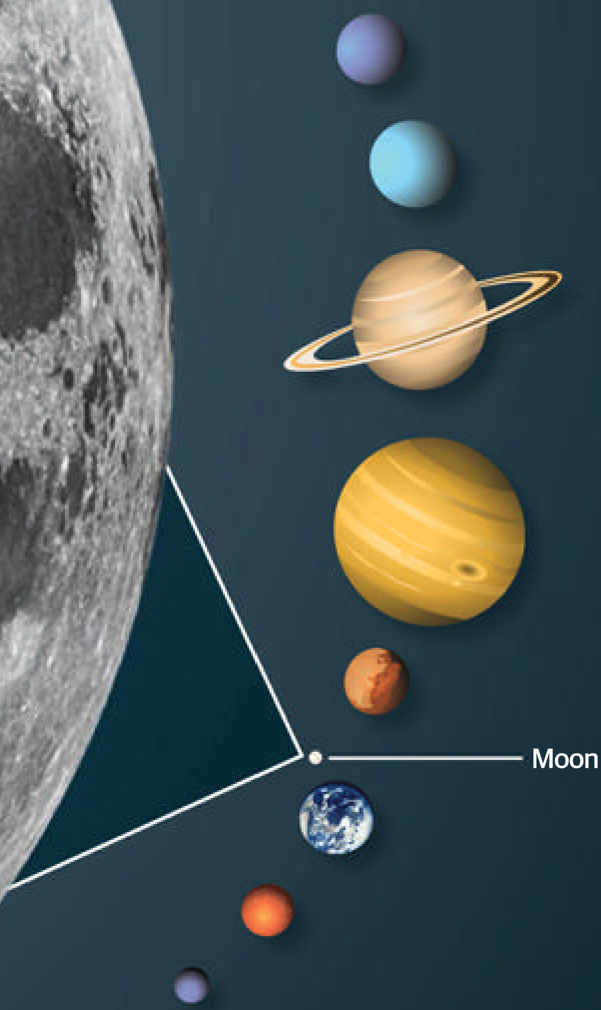
4. Coast
The transfer burn is timed so that by the time the spacecraft reaches the top of its orbit, the Moon has travelled to the same point in space

5. Landing
Once it gets close enough, the spacecraft fires its engines again to slow down just enough to be captured by the Moon into an orbit, or even more for a direct landing



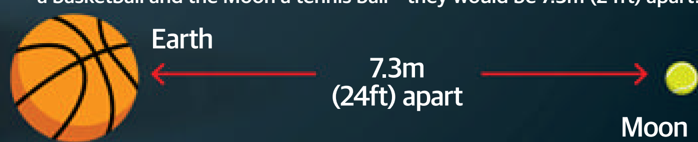
How big is the Moon?

The Moon is the fifth largest satellite in the Solar System and the biggest in comparison to its host planet



Distance from Earth

The Moon is currently 384,400km (238,855mi) away from Earth but is gradually moving away at a rate of 3.82cm (1.5in) a year. If the Earth was a basketball and the Moon a tennis ball – they would be 7.3m (24ft) apart.



Top sights to see on the Moon

Seen from Earth, the most obvious features on the Moon are the 'maria' or seas. These are vast plains of solidified lava that originally bled for tens of millions of years from the puncture wounds of asteroid impacts. They are darker than the rest of the Moon's crust because of the iron compounds in the basalt minerals. The Moon long ago cooled and set solid all the way through, so it doesn't have tectonic plates to throw up mountain ranges like Earth's. But asteroid impacts can do the same job in a fraction of the time. Large impacts create mountain ridges around their rims, such as the Montes Rook which form a ring 500 kilometres (310 miles) wide around the Mare Orientale. Where an impact crater hasn't been filled in by lava to form a mare, there is also a central mountain formed where the crust rebounded from the initial impact. Impacts can fling debris out over hundreds of kilometres. These form spokes of lighter asteroid material overlaid on the darker lunar regolith. Tycho crater in the southern hemisphere has rays that extend 1,500 kilometres (930 miles) from its rim.

When the Soviet Union sent Luna 3 to photograph the far side of the Moon for the first time, in 1959, they found it strangely lacking in maria. This is because the crust is thicker on the far side, so asteroid impacts didn't punch all the way through to the magma beneath. Instead the terrain is more irregular, thrust into a jumble of spires by the shockwaves from ancient impacts on the opposite side that travelled through the Moon and burst out of the surface, like an exit wound. Without water or wind, the landscape is unweathered, so every mountain is sharp and jagged.

As well as mountains and craters, the Moon has twisting features that look like river valleys. Called 'rilles', these may have been caused by lava tubes that cooled and sank into the regolith. Hadley Rille, where Apollo 15 landed, runs along the base of the Apennine mountains. Schroter's Valley is the largest lunar rille. It begins at a crater six kilometres (3.7 miles) wide and meanders for hundreds of kilometres in a strip that is ten kilometres (6.2 miles) wide in places. In fact it's so big that it has another smaller rille formed by a second lava flow, running along it like a river meandering through a glacial valley.

Copernicus crater

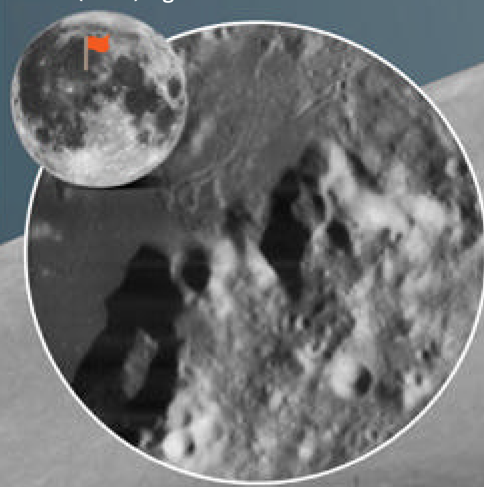
A relatively young crater at just 800 million years old. The mountains in the centre are almost as high as Ben Nevis.

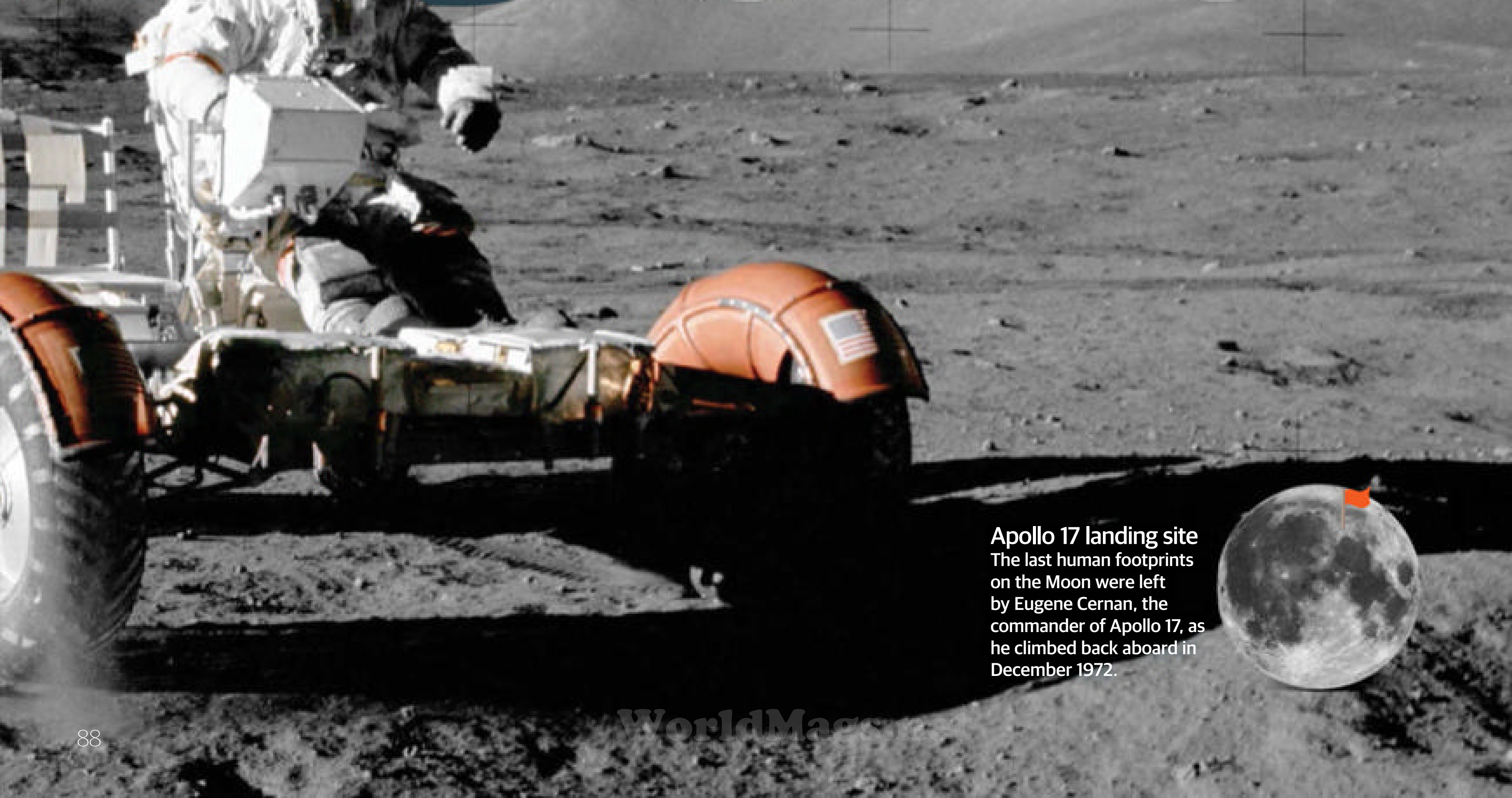
Apollo 11 landing site

Chosen because it was fairly flat, Neil Armstrong nevertheless had to manually pilot 6km (3.7mi) from the intended landing site to avoid a boulder field.

Tallest lunar mountain

Mons Huygens is part of the rim of the vast crater that filled with lava to become the Sea of Rains. It is 5.5km (3.4mi) high.



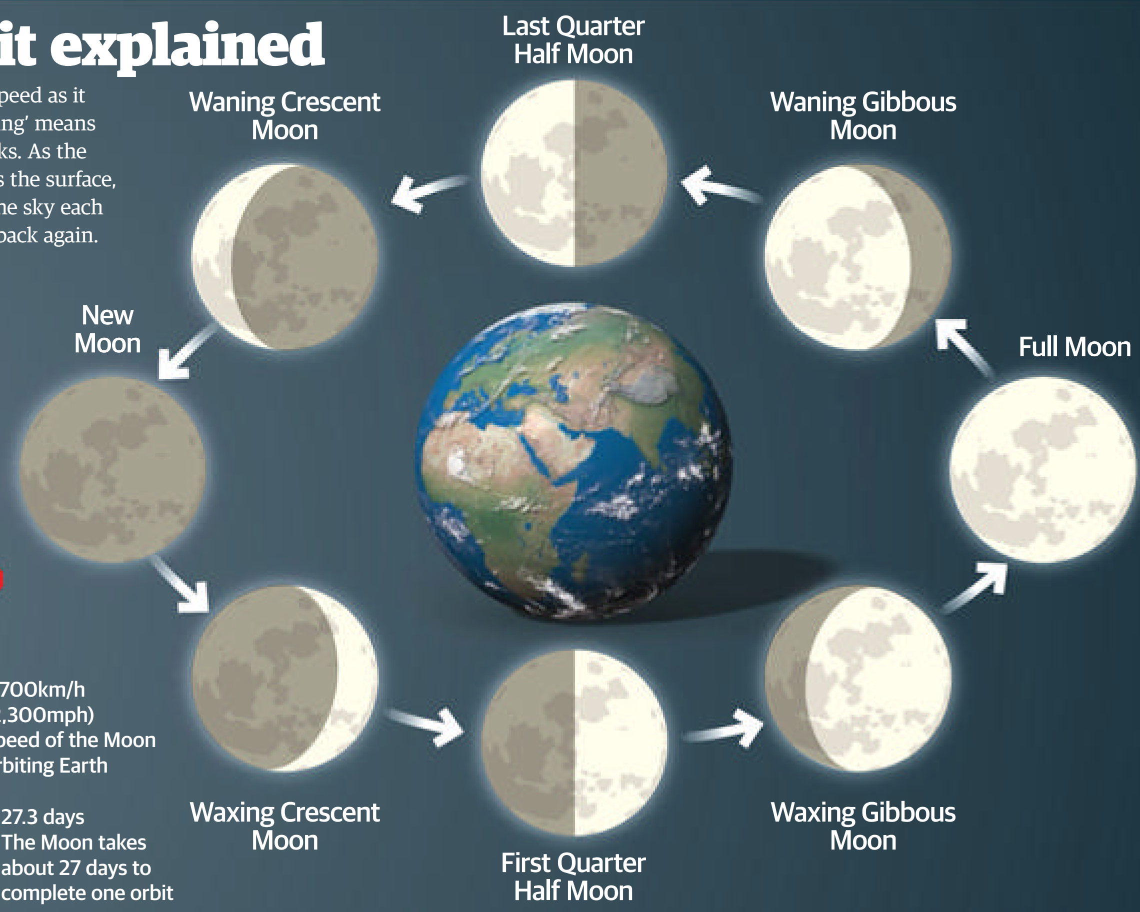


Apollo 17 landing site

The last human footprints on the Moon were left by Eugene Cernan, the commander of Apollo 17, as he climbed back aboard in December 1972.

The lunar orbit explained

The Moon spins on its axis at the same speed as it rotates around the Earth. This 'tidal locking' means a day on the Moon lasts almost four weeks. As the day/night terminator creeps slowly across the surface, we see a different phase illuminated in the sky each night, from new Moon to full Moon and back again.



The Moon's orbit is oval shaped

Perigee
363,400km/225,800mi (distance when closest to Earth)

Apogee
405,500km/252,000mi (distance when farthest to Earth)

16km/h (10mph)
Speed of the Moon's rotation

3,700km/h (2,300mph)
Speed of the Moon orbiting Earth

27.3 days
The Moon takes about 27 days to complete one orbit

The Moon in numbers

0.1654g
Surface gravity on the Moon, where you'd be a sixth your Earth weight

1,738km
Radius of the Moon – just over a quarter of Earth's

5,000metres
Height of the highest mountains on the Moon – taller than Mont Blanc

1972
The last time anyone stepped foot on the Moon

30%
Increase in brightness of the Moon when closest to Earth

135days
to get to the Moon by car travelling at 70mph

Weather forecast

100°C
-153°C

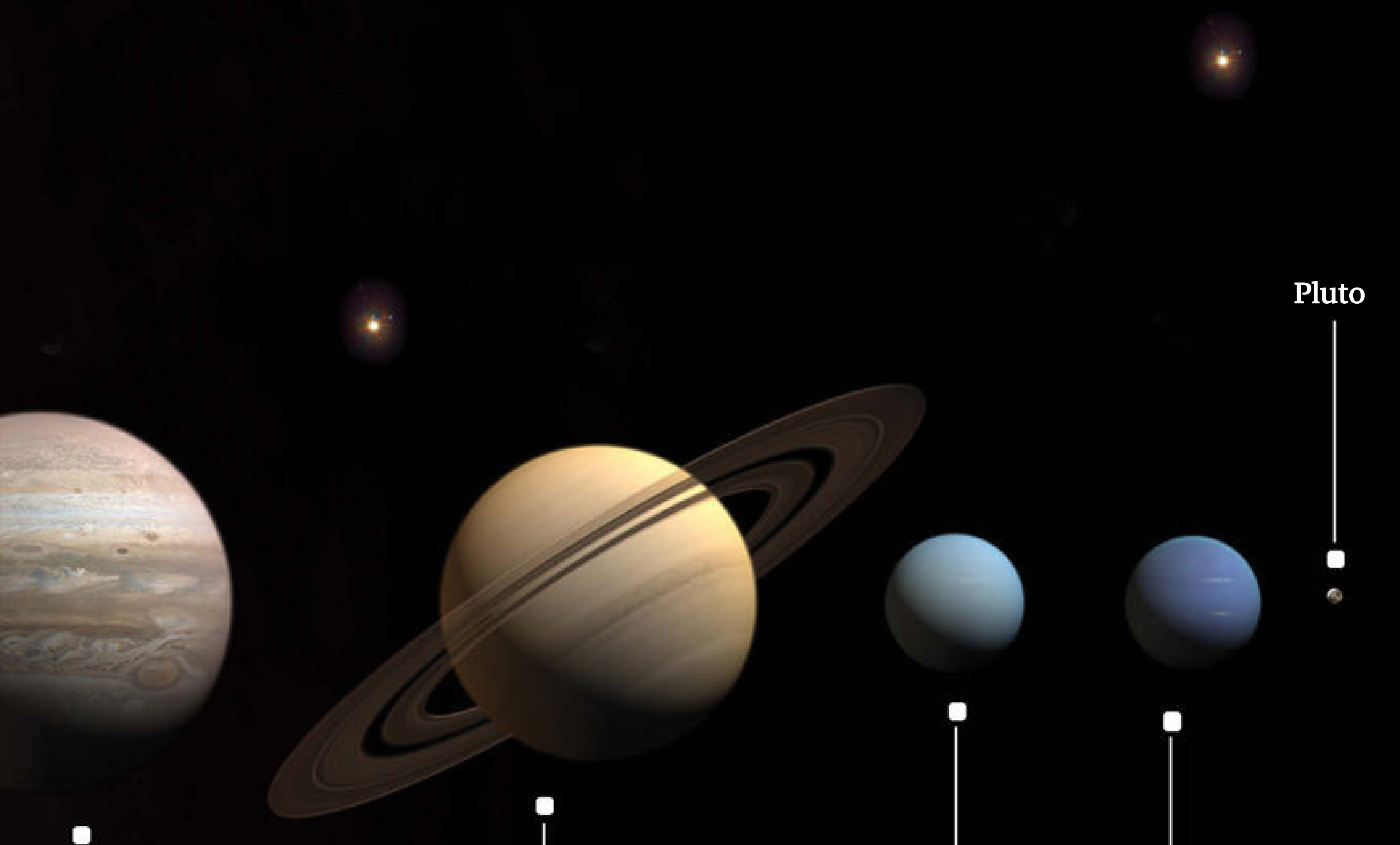
The Moon has virtually no atmosphere, just a sprinkling of evaporating atoms. So there is no wind to create weather systems. In direct sunlight the ground heats to over 100°C (212°F) but in the shade of a crater it can be as low as -247°C (-413°F).

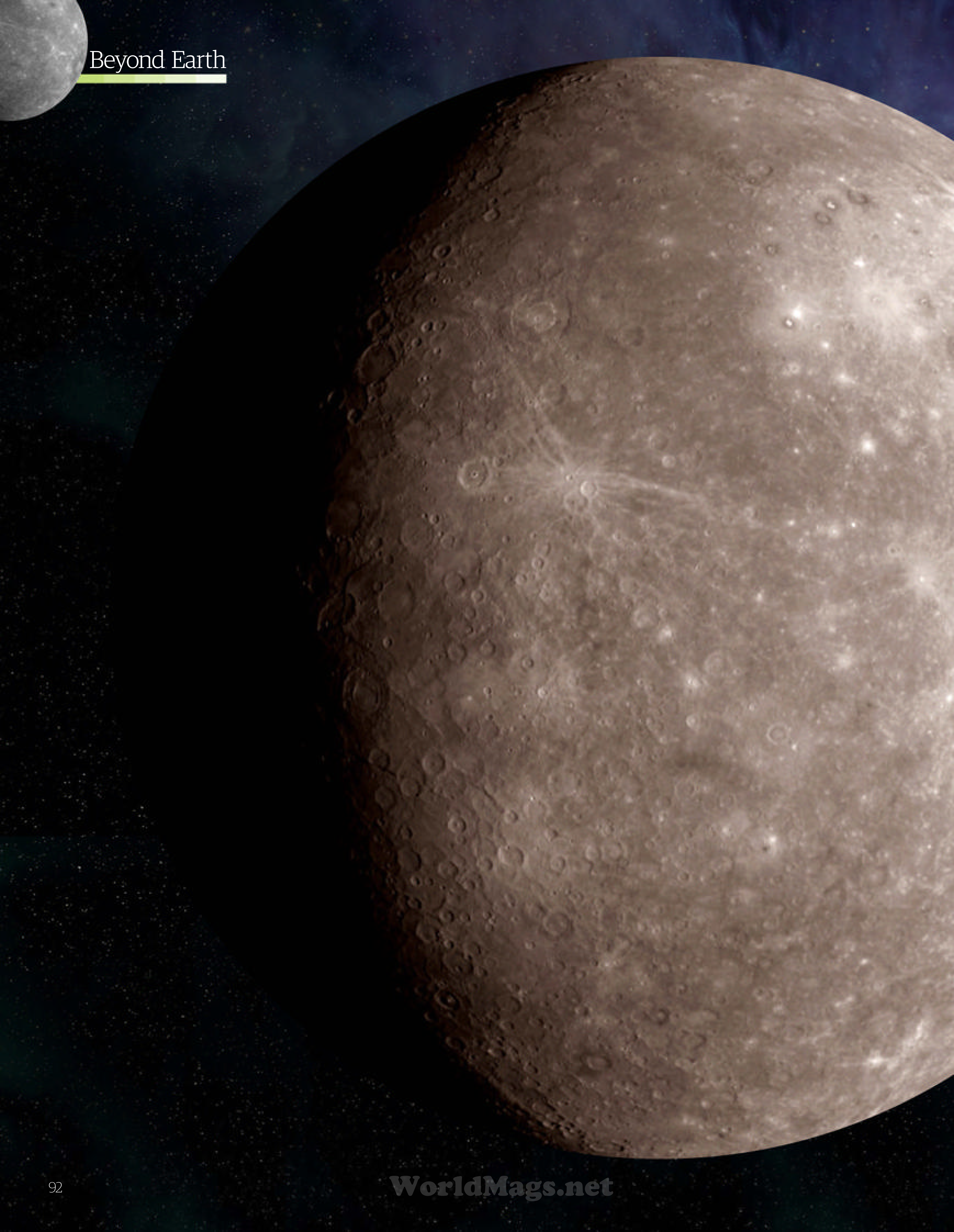
Hours in a lunar day, sunrise to sunrise

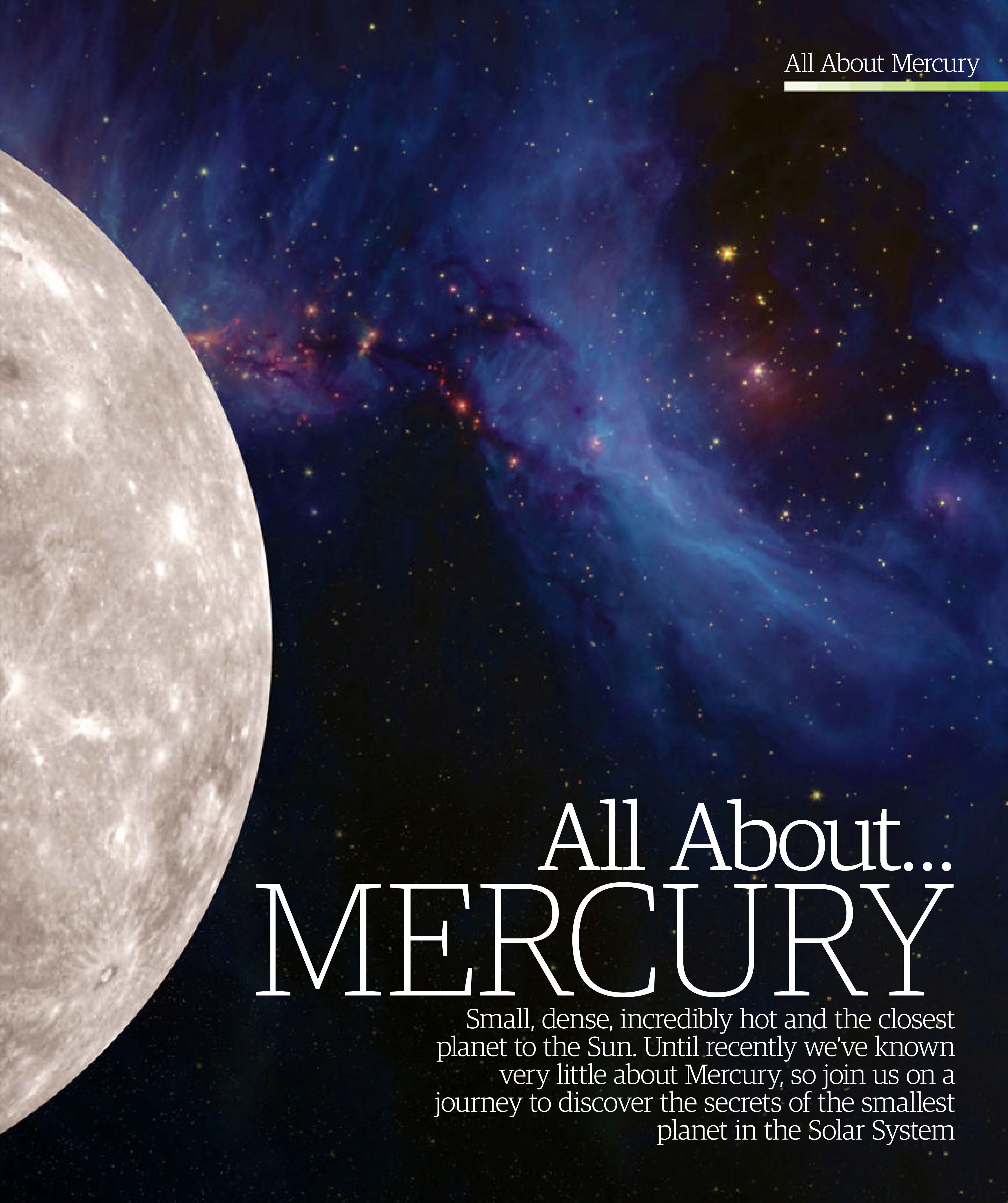
Beyond Earth

Explore the planets that neighbour Earth within our Solar System

Earth







All About... MERCURY

Small, dense, incredibly hot and the closest planet to the Sun. Until recently we've known very little about Mercury, so join us on a journey to discover the secrets of the smallest planet in the Solar System

Every planet is unique, but Mercury is a planet of paradoxes and extremes, and that's just based on what we know so far. It's the innermost planet, the smallest planet and has the most eccentric orbit. We've known about its existence since the third millennium BC, when the Sumerians wrote about it. But they thought that it was two separate planets – a morning star and an evening star – because that's just about the only time you can see it due to its closeness to the Sun. The Greeks knew it was just one planet, and even that it orbited the Sun (long before acknowledging that the Earth did, too). Galileo could see Mercury with his telescope, but couldn't observe much.

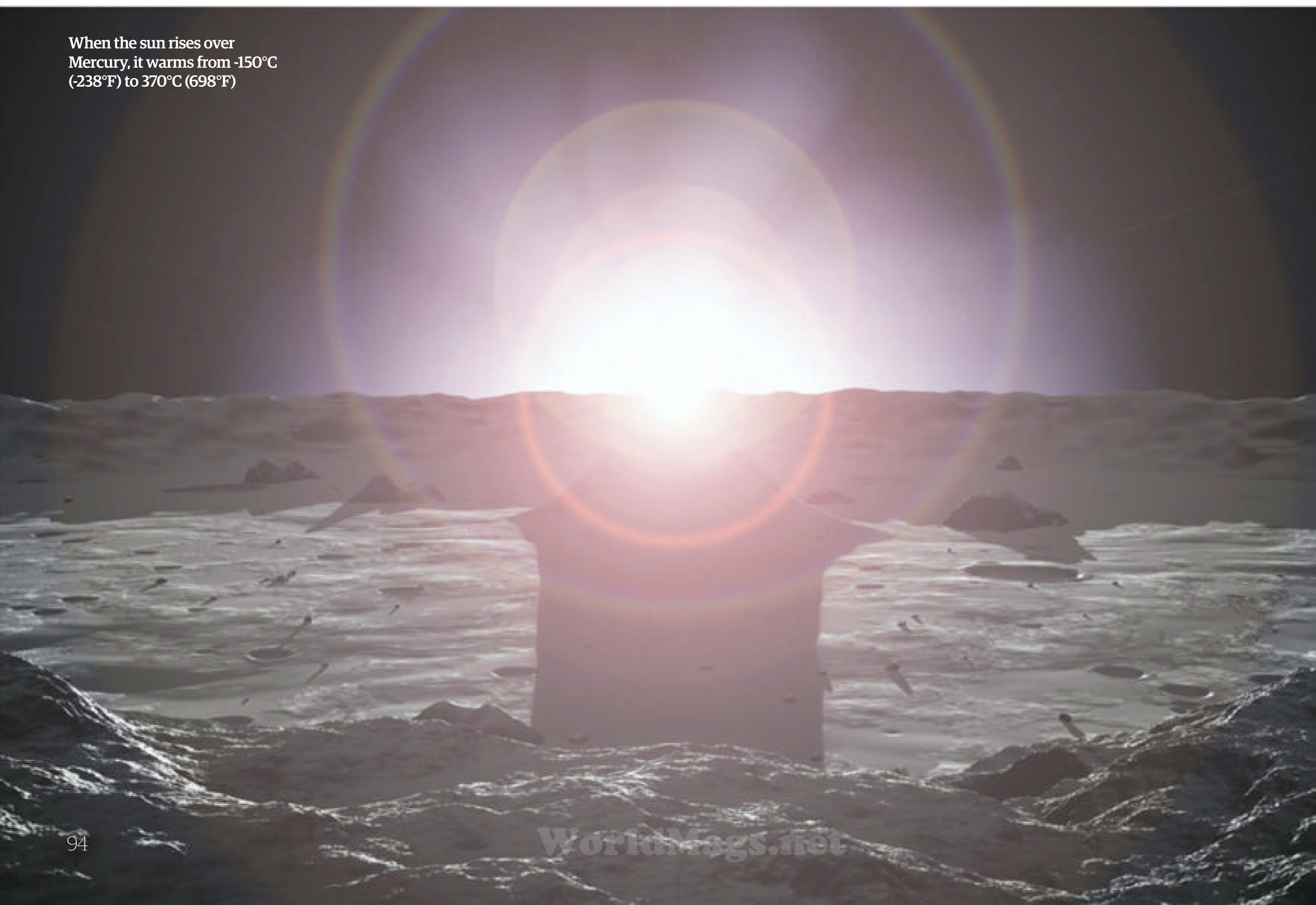
This little planet has a diameter that's 38 per cent that of Earth's diameter – a little less than three Mercurys could fit side by side Earth. It has a diameter of about 4,880 kilometres (3,032 miles). There are two moons in the Solar System that are bigger than Mercury, but the Earth's Moon is only about a 1,000 kilometres (621 miles) smaller. In surface area, it's about ten per cent that of Earth (75 million square kilometres or 29 million square miles), or about twice the size of Asia if you could flatten it out. Finally, in volume and mass Mercury is about five per cent that of Earth. Volume-wise that means that 18 Mercurys could fit inside one Earth. While it's small, it's incredibly dense; almost on par with Earth's density due to its heavy iron content.

Mercury is odd in other ways, too. It's tilted on its axis just like Earth (and all the planets in the Solar System), but its axial tilt is only 2.11 degrees away from the plane of the ecliptic. Contrast that with the Earth's tilt at 23.4 degrees. While that causes the Earth's seasons, Mercury has no seasons at all. It's simple – the side that faces the Sun is incredibly hot, and the side away from the Sun is incredibly cold. There's also no atmosphere to retain any heat.

Mercury rotates once every 58.6 days, and revolves around the Sun once every 88 days. For a very long time, we thought Mercury rotated synchronously, meaning that it kept the same side facing the Sun at all times (like the Earth's Moon does), and rotated once for each orbit. Instead, it rotates one and a half times for every trip around the Sun, with a 3:2 spin-orbit resonance (three rotations for every two revolutions). That means its day is twice as long as its year. Even stranger than this, when Mercury is at its perihelion (closest to the Sun), its revolution is faster than its rotation. If you were standing on the planet's surface, the Sun would appear to be moving west in the sky, but then stop and start moving very slowly eastward for a few days. Then as Mercury starts moving away from the Sun in its rotation (known as aphelion), its revolution slows down and the Sun starts moving westward in the sky again. Exactly how this might appear to you would depend greatly on where you were located on the planet and where the Sun was in the sky overhead. In some places it might look like there were multiple stops, reverses and starts in the rising and setting of the Sun, all in one day. Meanwhile, the stars would be moving across the sky three times faster than the Sun.

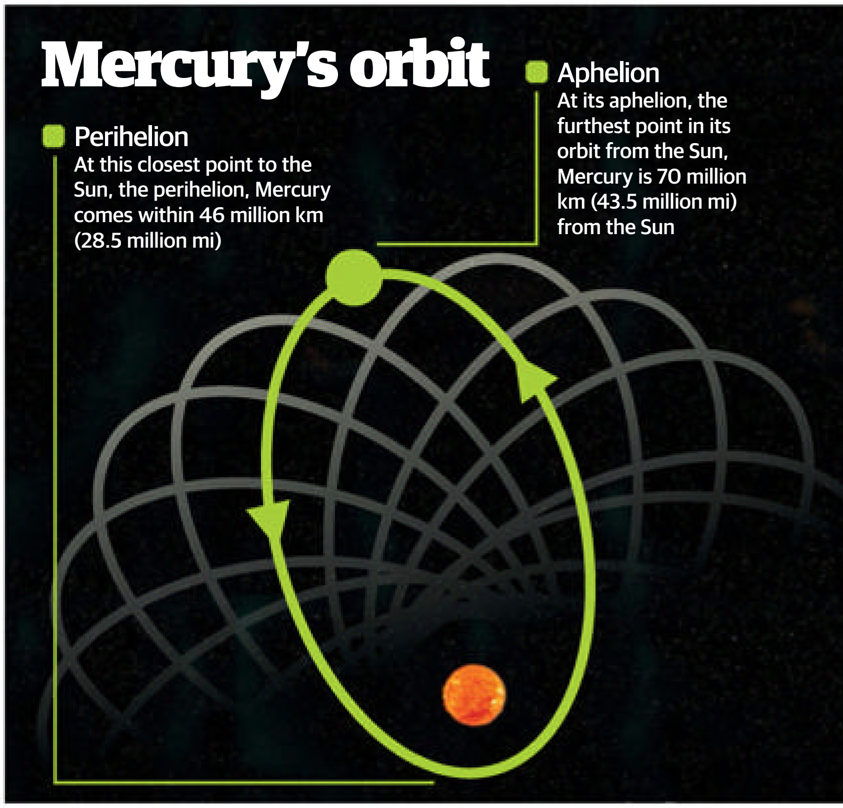
Mercury has the most eccentric orbit of any planet, meaning it's nowhere near a perfect circle. Its eccentricity is 0.21 degrees, resulting in a very ovoid orbit. This is part of the reason for its extreme temperature fluctuations as well as the Sun's unusual behaviour in its sky. Not only is it eccentric, it's also chaotic. At times in Mercury's orbit, its eccentricity may

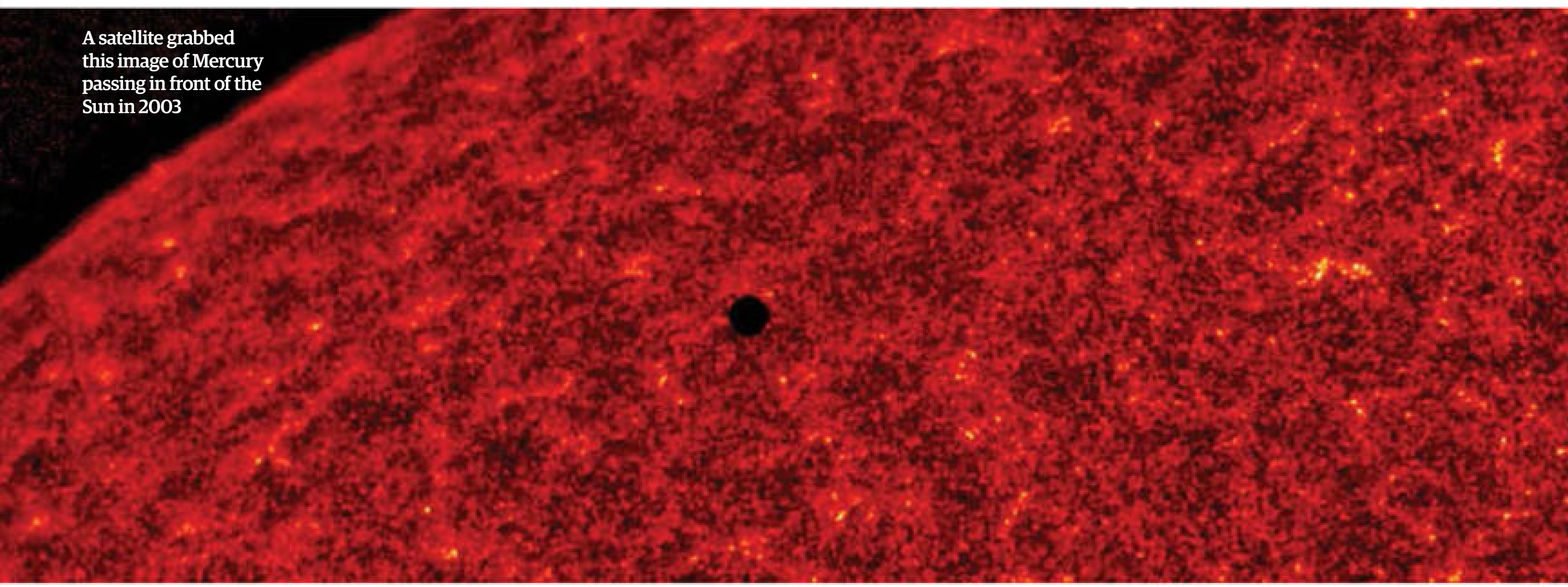
"Mercury has a diameter of 4,880km (3,032 mi); the Sun's diameter is 1,392,000km (865,000 mi)"

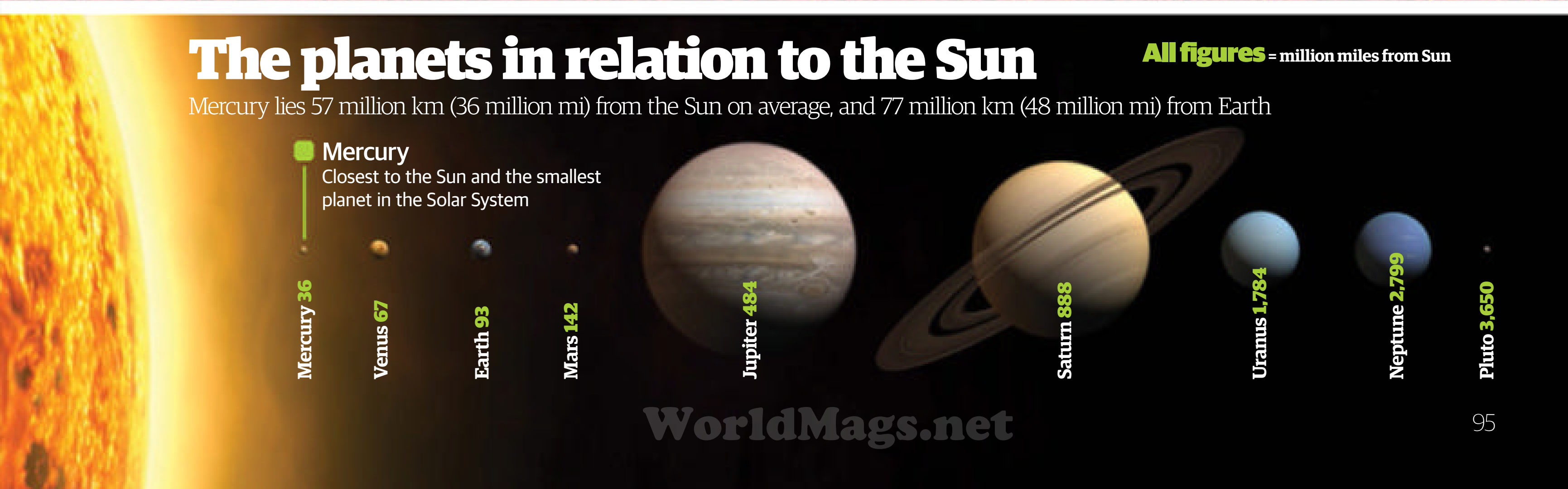

When the sun rises over Mercury, it warms from -150°C (-238°F) to 370°C (698°F)

be zero, or it may be 0.45 degrees. This is probably due to perturbations, or interactions with the gravitational pulls of other planets in space. These changes have happened over millions of years, and currently Mercury's orbit – specifically its perihelion – is changing by 1.56 degrees every 100 years. That's much faster than Earth's advance of perihelion, which is 0.00106 degrees every century. Some models show that increases in perturbations could cause Mercury to collide with Venus millions of years from now, but it's a very small chance.

Mercury's chaotic, eccentric orbit is inclined from the Earth's ecliptic plane by seven degrees. Because of this, transits of Mercury – when the planet is between the Earth and the Sun in its rotation – only occur about once every seven years on average. But like so many things about Mercury, its averages don't tell the whole story. For example, there was a transit of Mercury (when it appears to us as a small black dot across the face of the Sun) in 1999, in 2003, and in 2006… but the next one won't happen until 2016. They usually happen in May (at aphelion) or November (at perihelion), and the latter come more frequently. Transits may also be partial and only seen in certain countries. They're occurring later as the orbit changes. In the early 1500s, they were observed in April and October.




A satellite grabbed this image of Mercury passing in front of the Sun in 2003

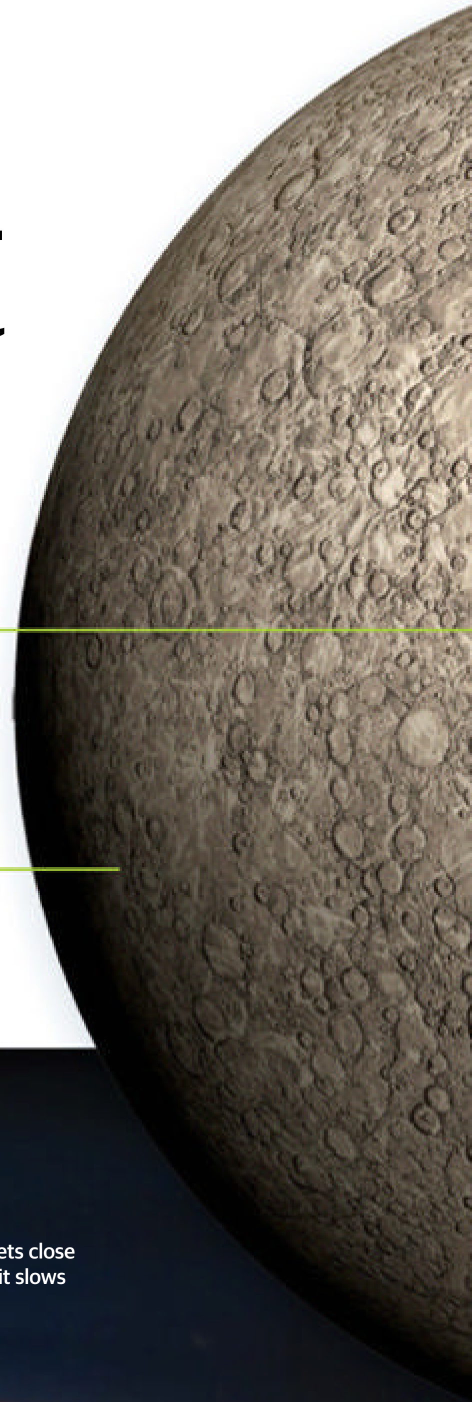


Mercury inside and out

Mercury has a huge core and a higher concentration of core iron than any other planet

Mercury contains about 30 per cent silicate materials and 70 per cent metals. Although it's so small, this make-up also means that it's incredibly dense at 5.427 grams per cubic centimetre, only a little bit less than the Earth's mean density. The Earth's density is due to gravitational compression, but Mercury has such a weak gravitational field in comparison to the Earth's. That's why scientists have decided that its density must be due to a large, iron-rich core. Mercury has a higher concentration of iron in its core than any other major planet in the Solar System. Some believe that this huge core is due to what was going on with the Sun while Mercury was forming. If Mercury formed before the energy output from the Sun stabilised, it may have had twice the mass that it does now. Then when the Sun contracted and stabilised, massive temperature fluctuations vaporised some of the planet's crust and mantle rock. Or a thinner mantle and crust may have always existed due to drag on the solar nebula (the Sun's cloud of dust and gas from which the planets formed) from the close proximity to the Sun itself. Our latest information from the Messenger spacecraft supports the latter theory, because it has found high levels of materials like potassium on the surface, which would have been vaporised at the extreme temperatures needed for the former theory.

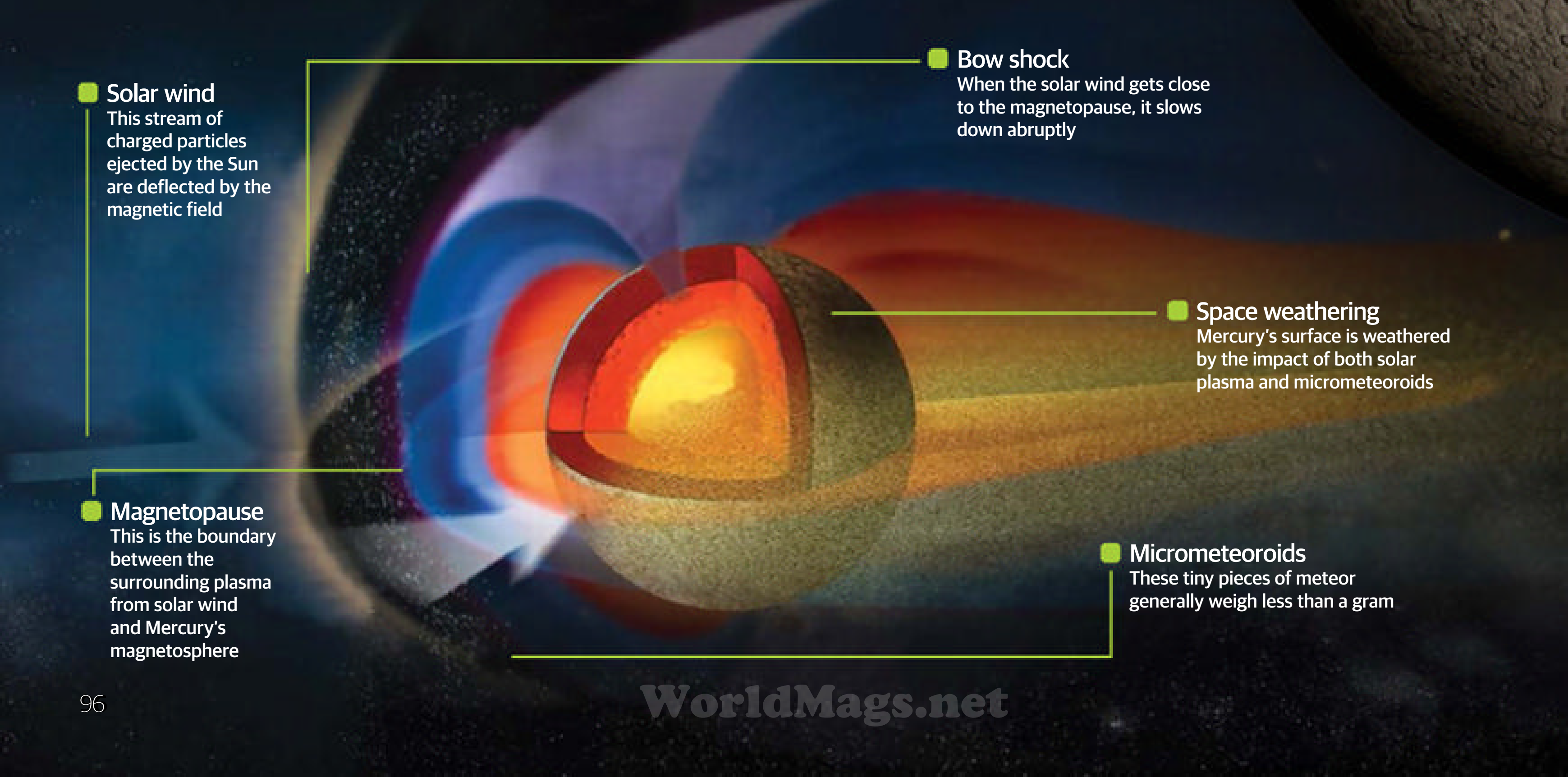
The structure of Mercury

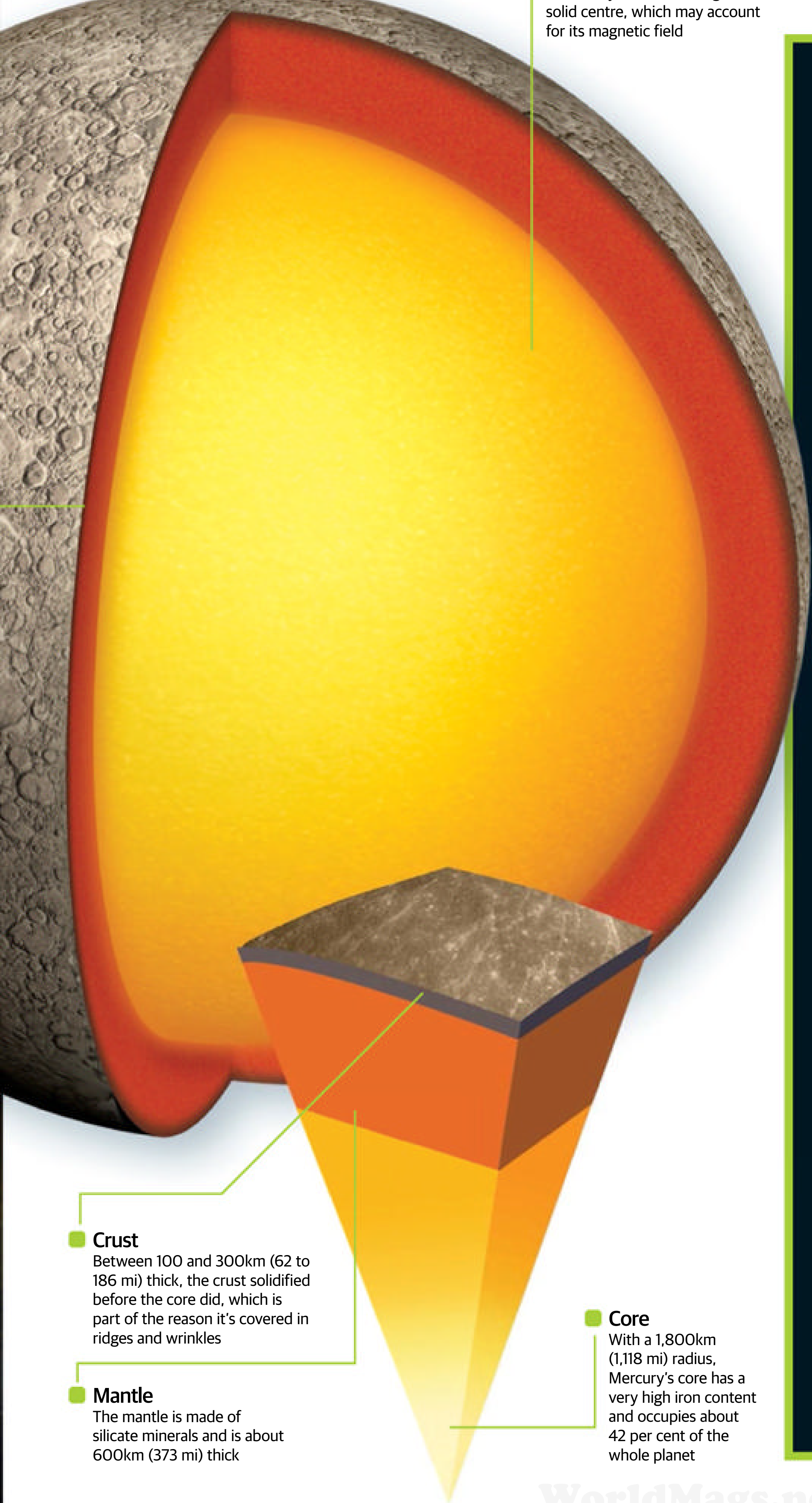


Huge impact
Because the mantle is so thin compared to the core, some believe that there may have been a huge impact of some type that stripped away some of the original mantle

Bombardment
The current crust may have formed after the bombardment, which was followed by volcanic activity that resulted in lava flows

Mercury's lack of atmosphere





Mercury in numbers

Fantastic figures and surprising statistics about Mercury

176 DAYS

Mercury revolves in 59 Earth days but it takes 176 days for the Sun to return to the same point in the sky

2nd

Densest planet in the Solar System after Earth

427°

Mercury's maximum surface temperature

2.5x bigger

The Sun appears two and a half times larger in Mercury's sky than it does in Earth's

45%

Until the Messenger spacecraft began imaging Mercury in 2008, we'd only ever seen this much of the planet

0 moons

Mercury is one of the few planets which has no moons or satellites captive within its gravity well

7x stronger

The Sun's rays are seven times stronger on Mercury than they are on Earth

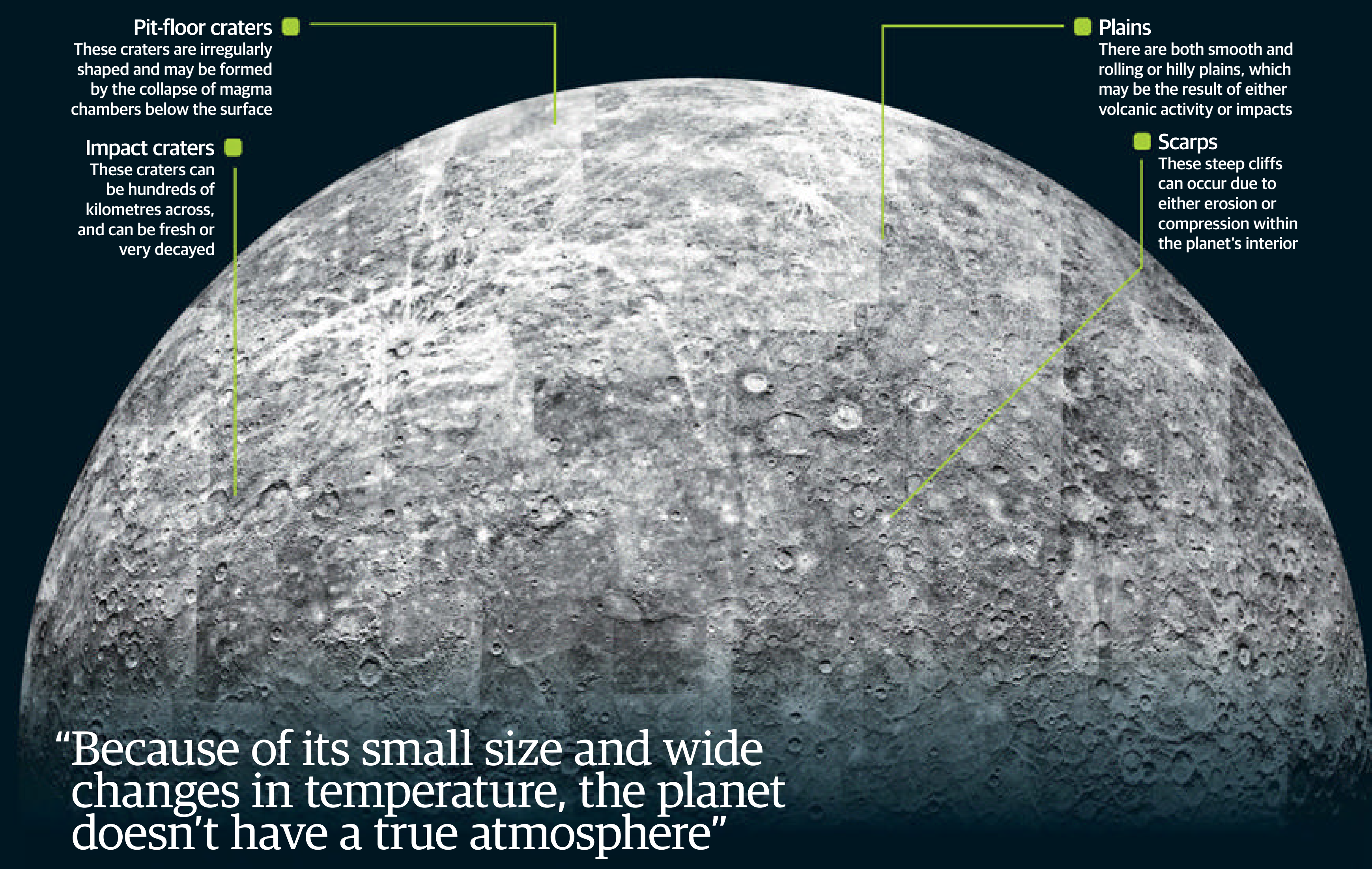
On the surface

Mercury is a planet of extreme variations in temperature, in its surface features and in its magnetic field

The surface of Mercury is not very well understood, but mapping by Mariner 10 and Messenger has revealed numerous craters and plains regions, crisscrossed with compression folds and escarpments. Not long after it formed, the planet was hit heavily and often in at least two waves by large asteroids and comets, which caused its extremely cratered surface. Couple this with periods of strong volcanic activity, which resulted in the smooth plains, and you have a very hilly surface.

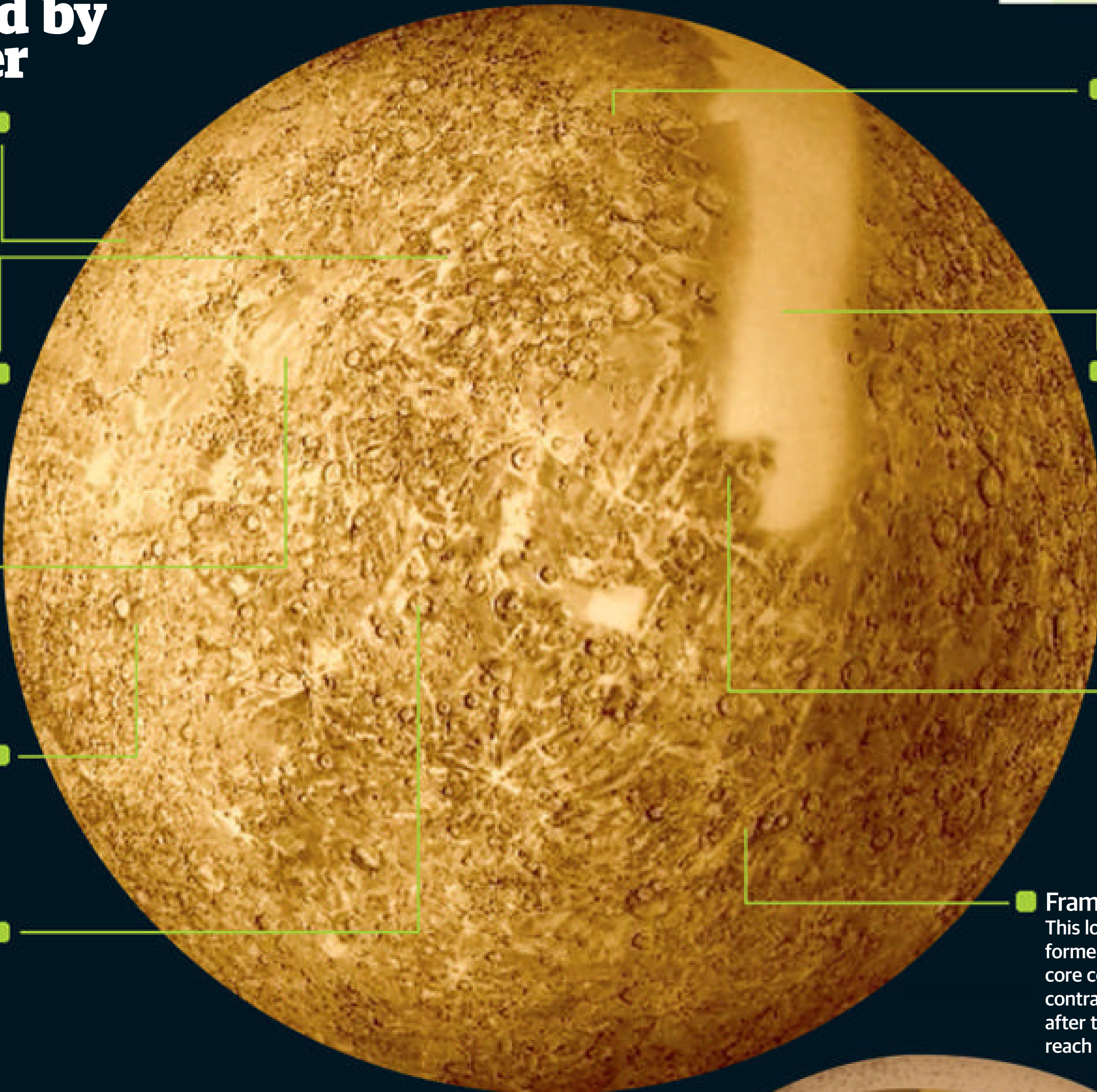
Mercury can reach 427 degrees Celsius (800 degrees Fahrenheit), and there's a big difference between the temperature at the equator and the temperature at its poles. It has the most temperature variations of any planet in the Solar System, getting as low as -183 degrees Celsius (-297 degrees Fahrenheit). There may be deposits of minerals and ice within craters near the poles. The deepest craters are located there, and are the most likely candidates to hold ice because they always stay shadowed, never rising above -173 degrees Celsius (-279 degrees Fahrenheit).

Because of its small size and wide changes in temperature, Mercury doesn't have a true atmosphere. It has an unstable exosphere, a very loose, light layer of gases and other materials. Gases within it include helium, oxygen and hydrogen, some of which come from solar wind. Minerals such as calcium and potassium enter the exosphere when tiny meteors strike the surface and break up bits of rock. Mercury also has a magnetosphere, formed when the solar wind interacts with its magnetic field. Although that magnetic field is only about one per cent as strong as Earth's, it traps in some plasma from the solar wind, which adds to its surface weathering. The Messenger spacecraft discovered that Mercury's magnetosphere is somewhat unstable, causing bundles of magnetic fields to be pulled out into space and wrapped into tornado-like structures by the passing solar wind. Some of these tornadoes are as long as 800 kilometres (497 miles), or about a third of the planet's size. Before Mariner 10 flew by Mercury, it was thought not to have a magnetic field at all. The current theory is that it is caused by a dynamo, much like Earth's magnetic field, which means that the planet has an outer core of



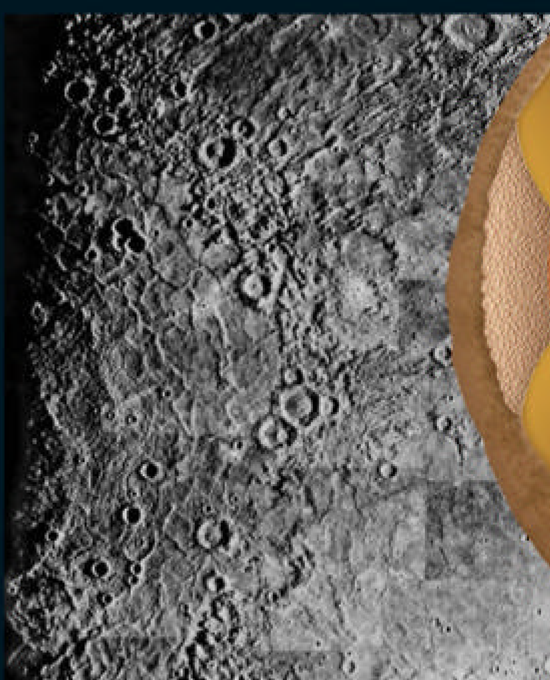
> "Because of its small size and wide changes in temperature, the planet doesn't have a true atmosphere"

Mercury mapped by Mariner

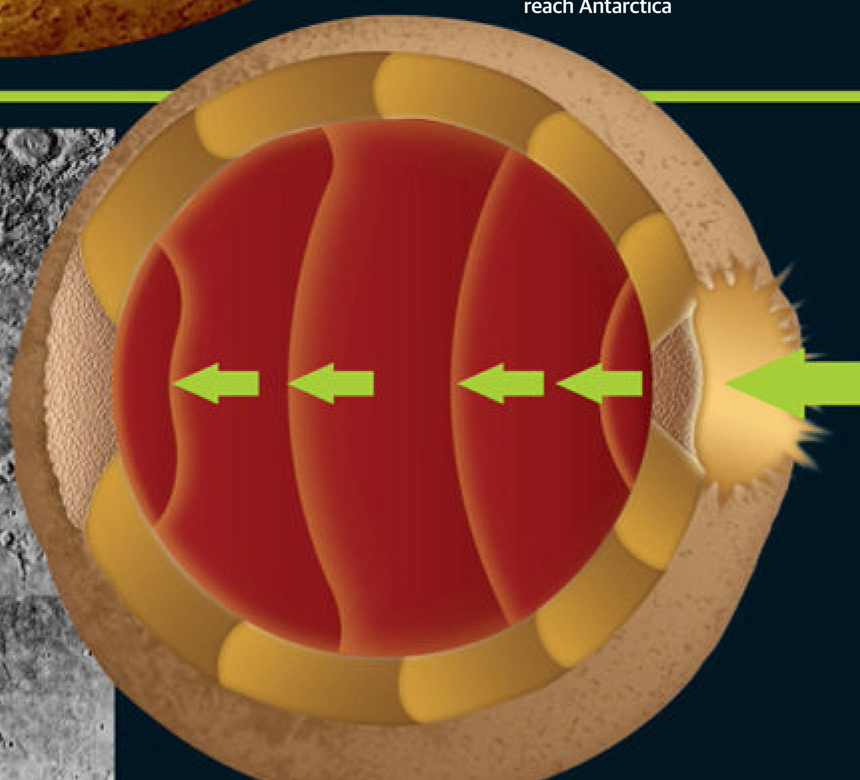


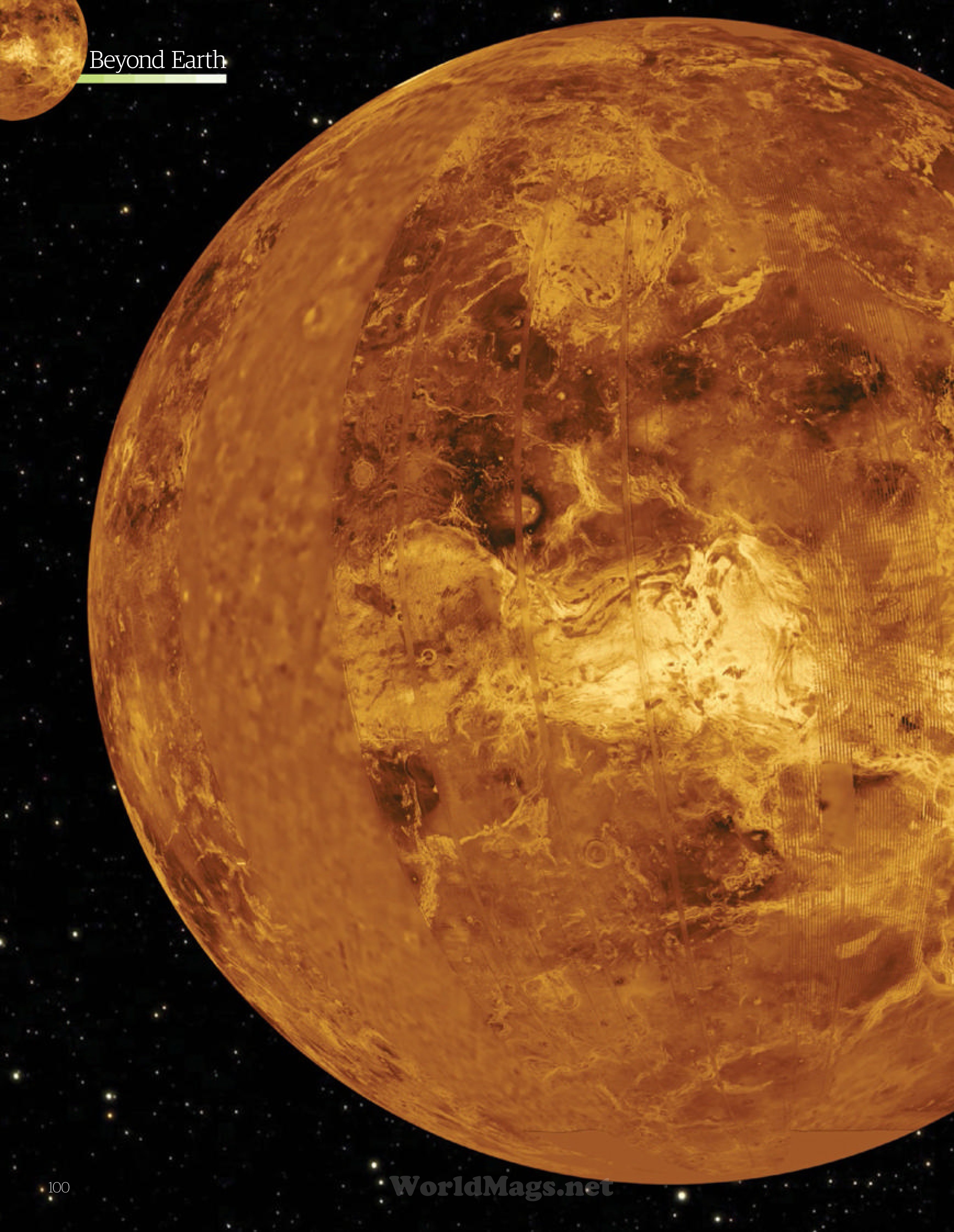
The Caloris Basin

This diagram shows how the large impact craters on Mercury's surface - and particularly the Caloris Basin - have impacted the rest of the planet. At the antipode (a point on the other side of the planet exactly opposite of the basin), the ground is very uneven, grooved and hilly. It's called the Chaotic Terrain because it stands out so much among the otherwise smooth plains. The terrain may have formed due to seismic waves or material actually ejected from the antipode.



The image of Mercury's surface was taken at a distance of about 18,000km (11,100 mi)





All About... VENUS

Venus is the most Earth-like planet in the Solar System, but there are a few key differences between the two planets, such as clouds of acid and temperatures hot enough to melt lead. Read on to discover more about Earth's 'evil twin'

Venus, named after the Roman goddess of love and beauty, is a study in contradictions. It was likely first observed by the Mayans around 650 AD, helping them to create a very accurate calendar. It's well-known to us because of its apparent magnitude, or brightness, in our sky – the second-brightest after our own Moon. It's most visible at sunrise and sunset, and like Mercury was thought of as two different planets by the Ancient Egyptians – Morning Star and Evening Star. It's the second-closest planet to the Sun, the closest planet to Earth, and the sixth-biggest planet in the Solar System.

Venus is often described as the Earth's 'twin' or 'sister planet'. Like Earth, Venus is a rocky planet, with a mass that's 81.5 per cent of the Earth's mass. It's 12,092 kilometres (7,514 miles) in diameter, which is just 650 kilometres (404 miles) shy of Earth's diameter. Both planets have relatively young surfaces, with few craters. But that's where the similarities end. Venus has been called possibly one of the most inhospitable planets in the Solar System, because lurking beneath its dense cloud cover is an atmosphere that's anything but Earth-like, which is why some astronomers have taken to calling it Earth's 'evil twin' instead.

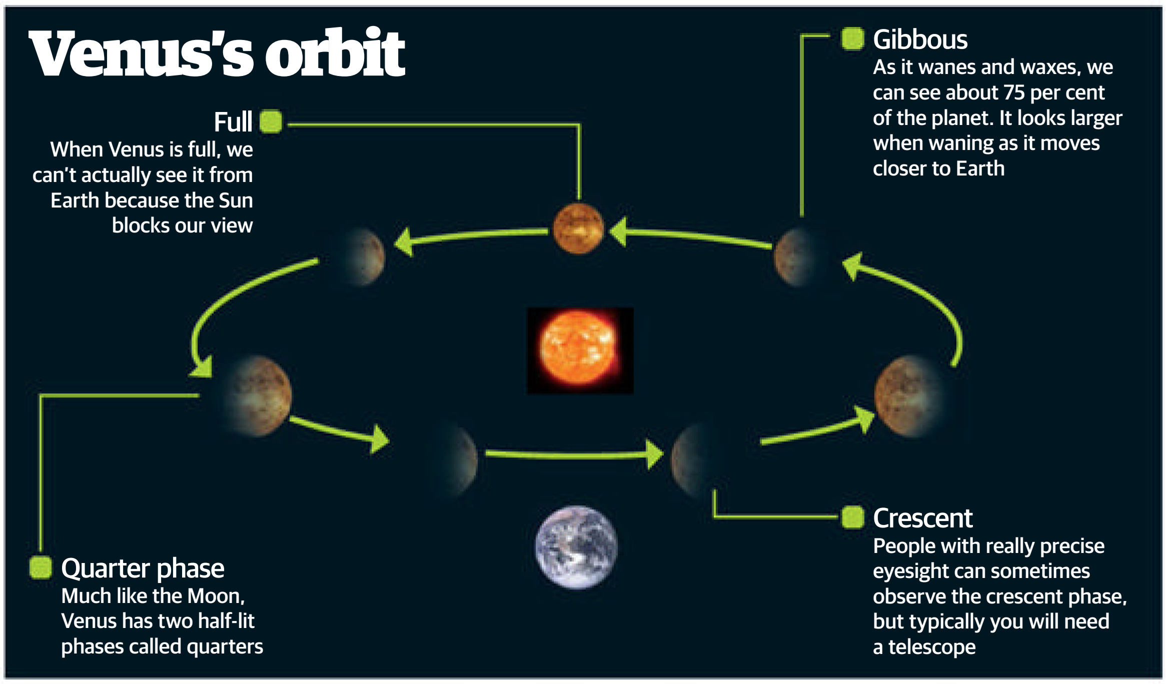
Of all the planets, Venus has the most circular orbit, with an eccentricity (deviation from a perfect circle) of 0.68 per cent. By comparison, the Earth has an eccentricity of 1.67 per cent. Venus comes within 108 million kilometres (67 million miles) of the Sun on average. When it happens to lie between the Sun and the Earth – which occurs every 584 days – it comes closer to the Earth than any other planet. Around 38 million kilometres (24 million miles) close, that is. Because Venus's orbit around the Sun passes inside the Earth's orbit, it also goes through phases that go from new to full and back to new again. These phases are the different variations of light emanating from it as seen from the Earth, much like the Moon's phases. When Venus is new (not visible) it is directly between the Earth and the Sun. At full, it is on the opposite side of the Earth from the Sun. These phases were first recorded by Galileo in 1610.

The rarest of predictable events in our Solar System involve Venus. Known as transits of Venus, this only happens once every 243 years in a pattern. A transit is somewhat like a solar eclipse, occurring when the planet is between the Earth and the Sun. Transits of Venus happen eight years apart, then with gaps of 105.5 years and 121.5 years between them. The odd pattern has to do with the relationship between the orbital periods of the two planets. Usually they happen in pairs, but not always. During a transit, Venus looks like a tiny black disc passing across the Sun's surface. The first modern observation of a transit of Venus occurred in 1639, while the most recent was on 5 and 6 June 2012. The transits have always provided astronomers with lots of information about not only Venus, but our Solar System. The earliest helped gauge the size of the Solar System itself, while the one in 2012 is hoped to help us find planets outside our Solar System, or exoplanets.

> "Venus rotates clockwise, making a Venusian sidereal day last the equivalent of 243 days on Earth"

What else sets Venus apart? Its retrograde rotation. Every planet orbits the Sun anti-clockwise, and most of them rotate anti-clockwise, too. But Venus rotates clockwise, making a Venusian sidereal day last about 243 Earth days – incidentally one of the slowest rotations of any planet. But its orbit around the Sun lasts 224.7 days, making Venus's days longer than its years. All of this means that if you were standing on the surface of the planet, you'd see the Sun rise in the west and set in the east, but only every 116.75 Earth days or so.

Many astronomers have wondered why Venus has such a circular orbit and unusual rotation. All planets came from the solar nebula – matter left over from the formation of the Sun – but maybe Venus had a more violent beginning. One theory is that it formed from the collision of two smaller planets, which impacted at such high speeds that they simply fused together, leaving very little debris. Another is that the planet experienced other multiple impact events – and even had one or more moons – that caused its spin to reverse.

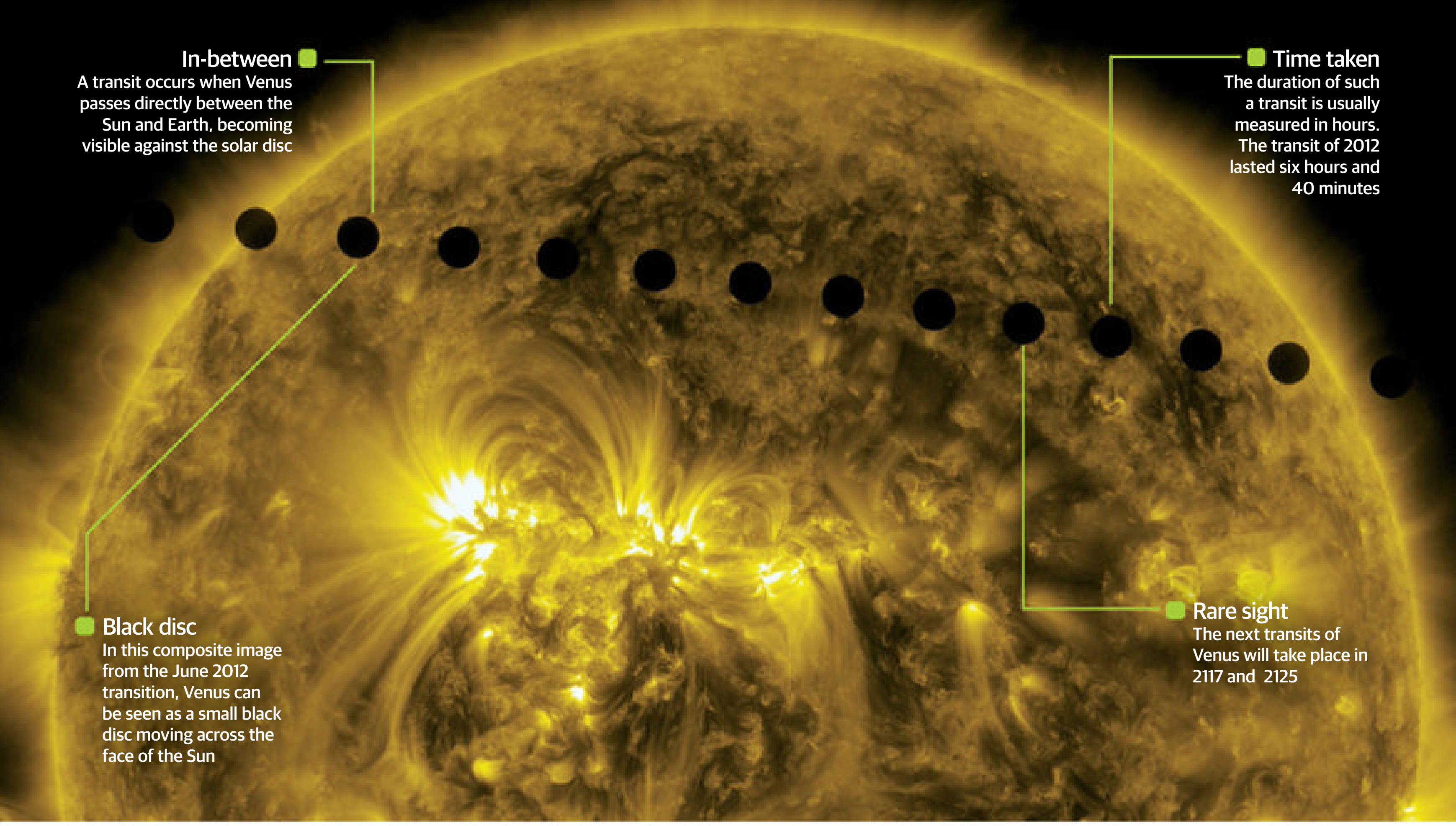


The planets in relation to the Sun

All figures = million miles from Sun

Venus lies 108 million km (67 million mi) from the Sun and 38 million km (24 million mi) from Earth

The transit of Venus



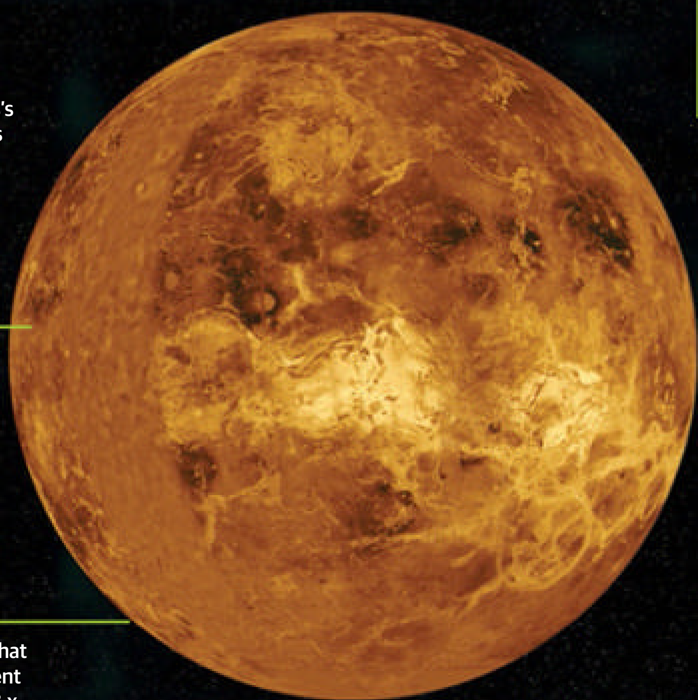
In-between
A transit occurs when Venus passes directly between the Sun and Earth, becoming visible against the solar disc

Time taken
The duration of such a transit is usually measured in hours. The transit of 2012 lasted six hours and 40 minutes

Black disc
In this composite image from the June 2012 transition, Venus can be seen as a small black disc moving across the face of the Sun

Rare sight
The next transits of Venus will take place in 2117 and 2125

Earth's twin planet



Diameter
Earth's diameter is just 650 kilometres greater than that of Venus – Earth's is 12,742 kilometres (7,918 miles). Venus's is 12,092 kilometres (7,514 miles)

Surface
Both planets have relatively young surfaces, without many craters

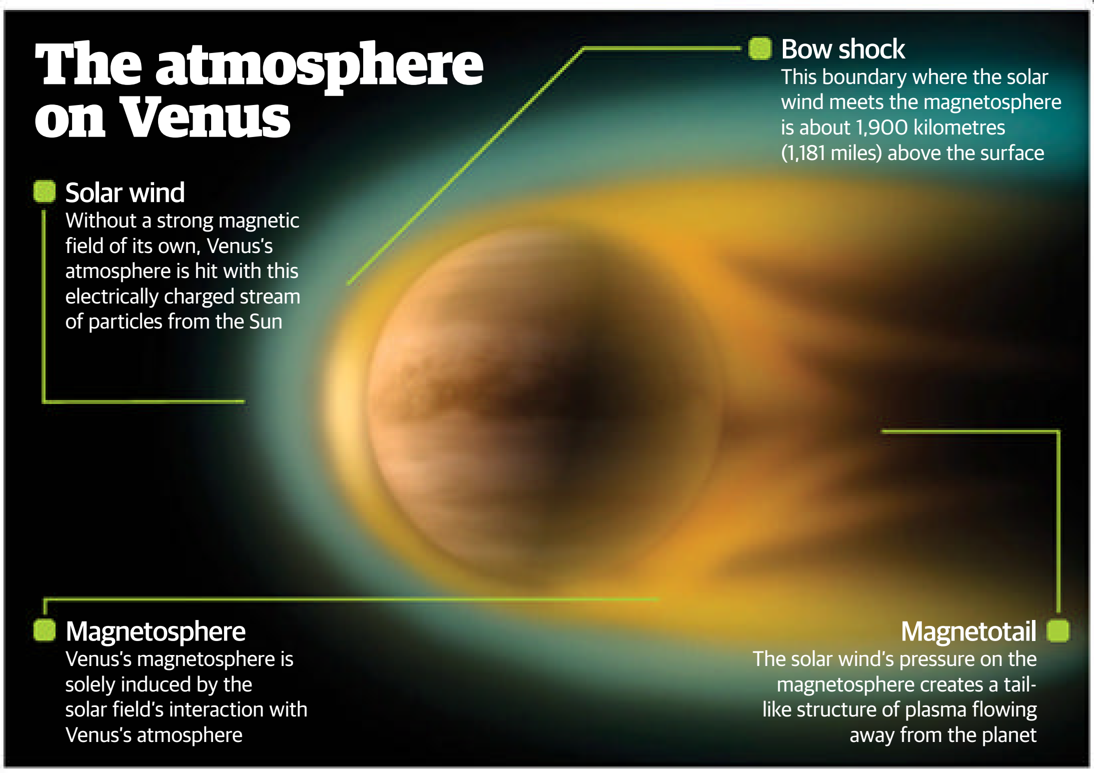
Mass
Venus has a mass that is about 81.5 per cent of Earth's, at 4.868 x 10^{24} kilograms

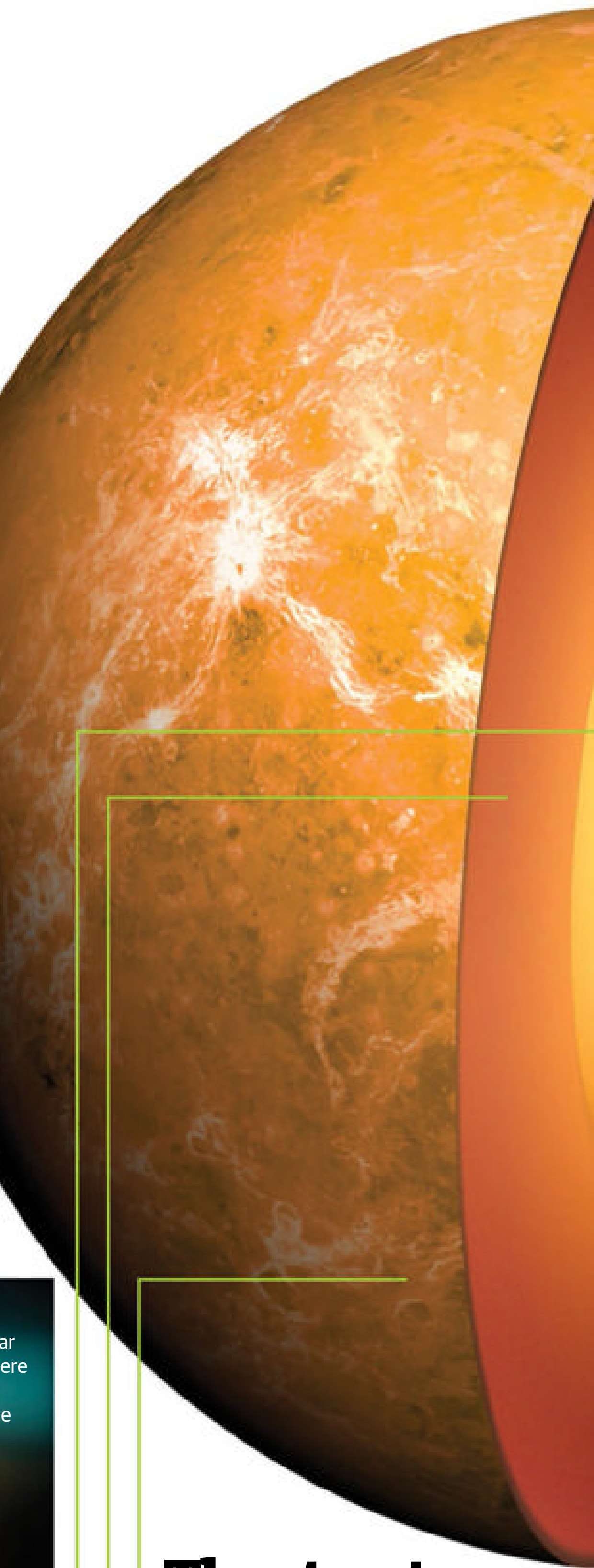
Venus inside and out

We don't know much of Venus's interior, and what we know of its atmosphere isn't pretty

While our knowledge of Venus's internal make-up is mostly based on speculation, we do know that it does not include a dynamo, like Earth's. A dynamo is a convecting, rotating fluid that conducts electricity and is responsible for a planet's magnetic field. Venus may have a liquid outer core and that conducts electricity, but does not convect and rotates too slowly to produce a dynamo. The Earth has a dynamo in part because its liquid core is hotter on the bottom than on the top, creating convection. Venus's core may be all one temperature. But why? Some astronomers believe that Venus was subject to an unknown event on its surface, which caused an end to plate tectonics on the surface and led to a cooling of the core. Venus's core could be completely solid, or it may be completely liquid. What we do know is that its magnetic field, which is incredibly weak, is caused by interactions between the ionosphere (ionised upper atmosphere) and the solar wind.

Venus has the densest atmosphere in the Solar System, with a mass about 90 times that of Earth's atmosphere. There's a heavy, sulphuric layer of clouds that scatter about 90 per cent of the sunlight that reaches them, which prevents viewing of the planet's surface and keeps it dim. Below the cloud layer is a layer of carbon dioxide, mixed with a bit of nitrogen. Pressure on the surface is 92 times that of Earth's surface. Although Venus is further away from the Sun than Mercury, its atmosphere creates a greenhouse effect that results in an incredibly hot temperature of 460 degrees Celsius (860 degrees Fahrenheit), while Mercury's maximum temperature is just over 420 degrees Celsius (788 degrees Fahrenheit). The temperature stays the same most of the time, and there are winds of up to 300 kilometres per hour (186 miles per hour). Some scientists believe that Venus once had an atmosphere more like Earth's, and even had oceans, but the greenhouse effect eventually evaporated all of the water.



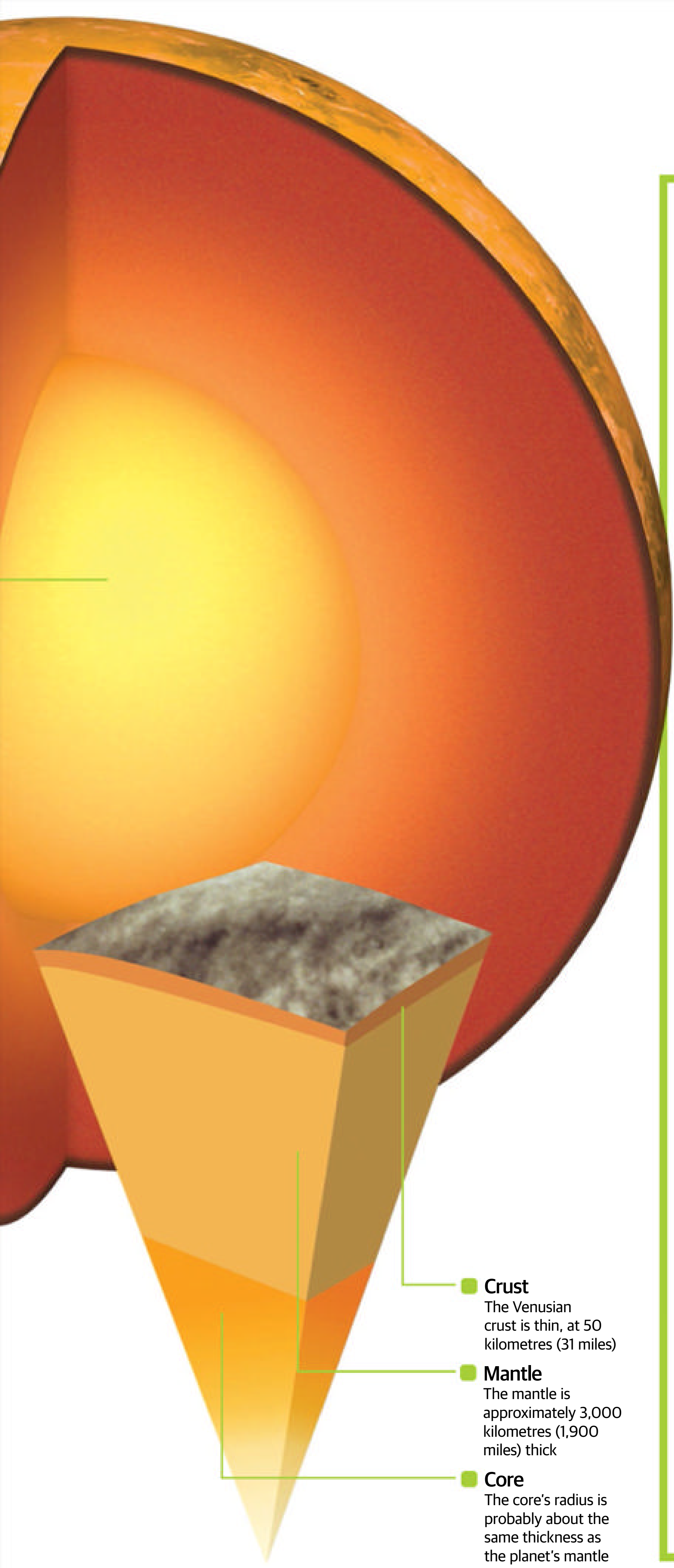


The structure of Venus

Crust
Venus's crust is mainly made up of silicate rocks

Mantle
The mantle is likely rocky and similar in composition to Earth's

Core
The core is probably molten metal, but how much of it is liquid and how much is solid remains a mystery



Crust
The Venusian crust is thin, at 50 kilometres (31 miles)

Mantle
The mantle is approximately 3,000 kilometres (1,900 miles) thick

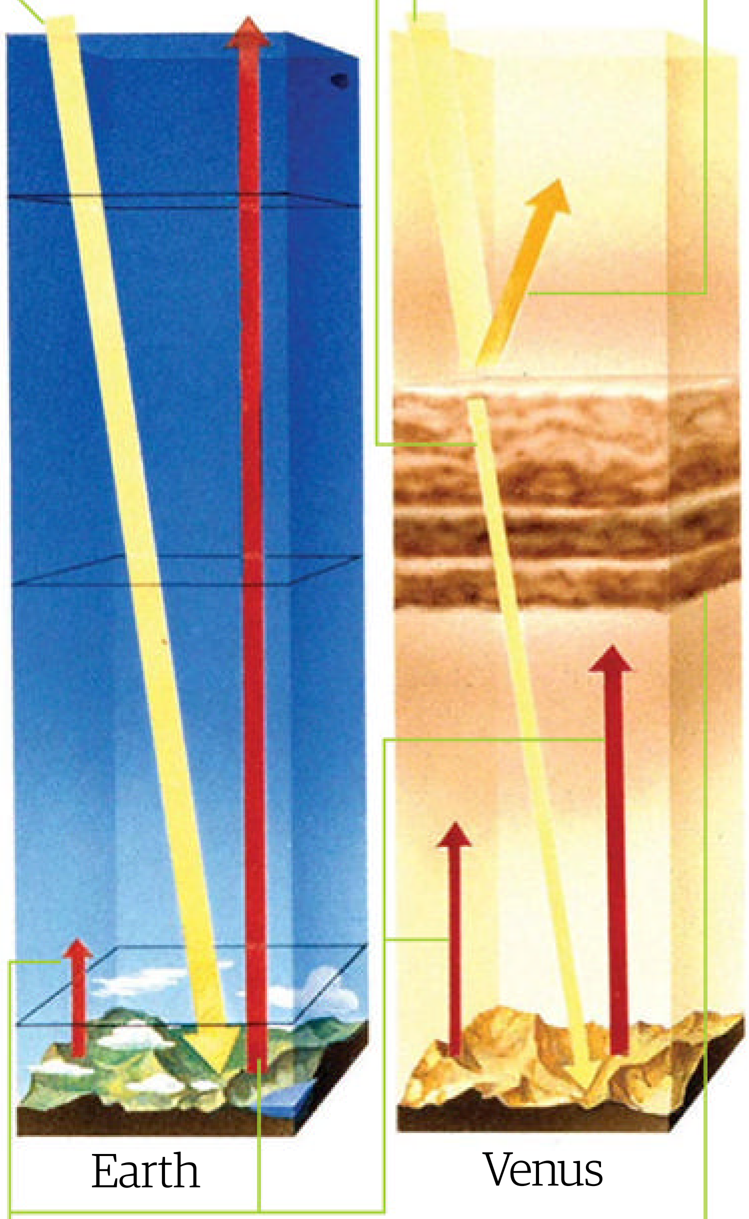
Core
The core's radius is probably about the same thickness as the planet's mantle

The greenhouse effect on Venus

How Venus's extreme and inhospitable temperatures are created

Incoming sunlight
Most of the sunlight passing through Earth's atmosphere makes it through. However, very little sunlight gets through Venus's thick atmosphere

Reflected sunlight
Most of the sunlight that reaches Venus is reflected away from the planet before reaching the surface



Infrared radiation
Both Venus and Earth emit infrared radiation but most of Venus's does not make it off the planet

Reflective clouds
The heavy cloud cover on Venus means that the planet stays incredibly hot, as most of its heat cannot escape from the planet's atmosphere

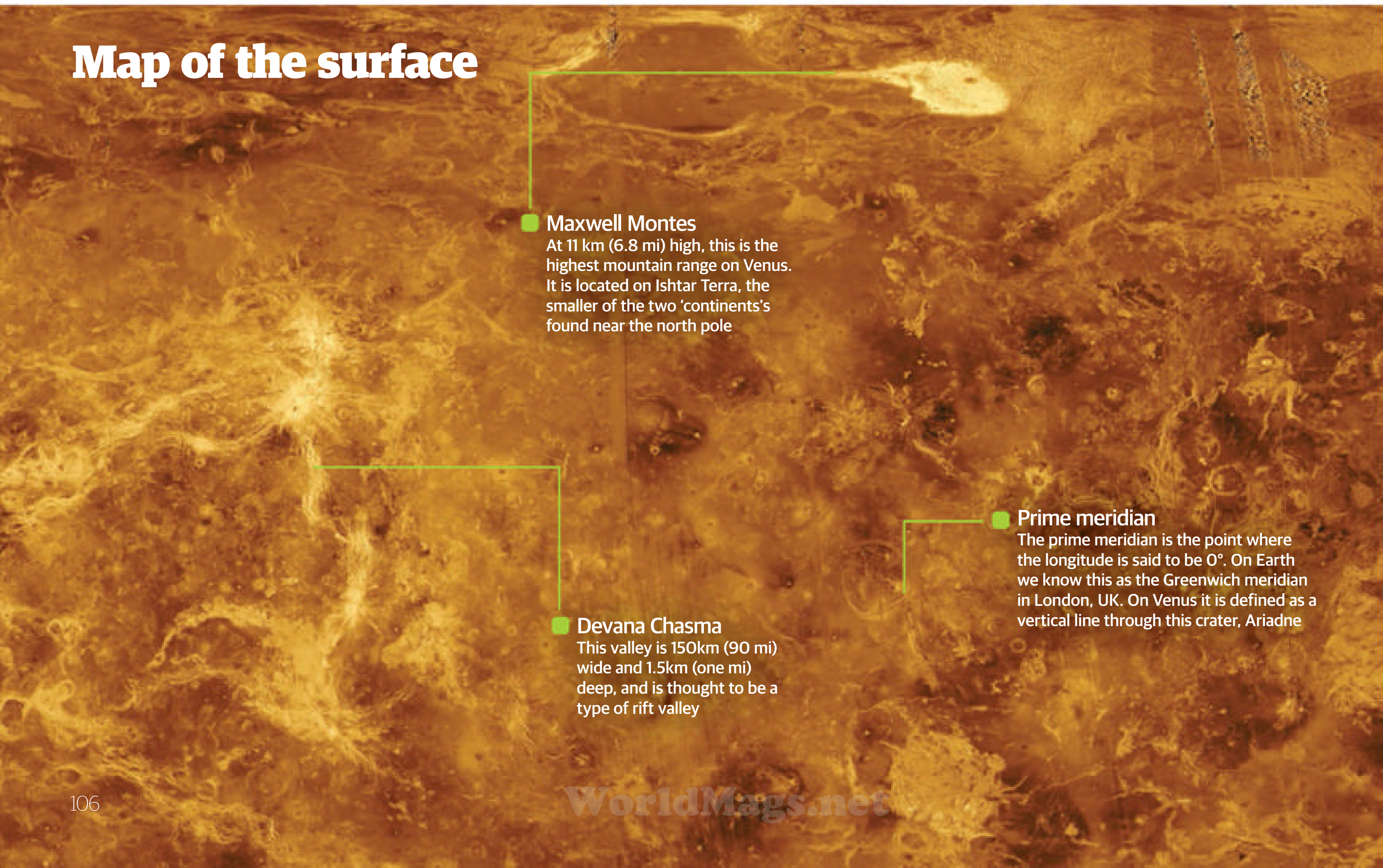
On the surface

Venus is smooth, with a young surface – but it is also covered in volcanoes and lava flows that may have lasted for millions of years

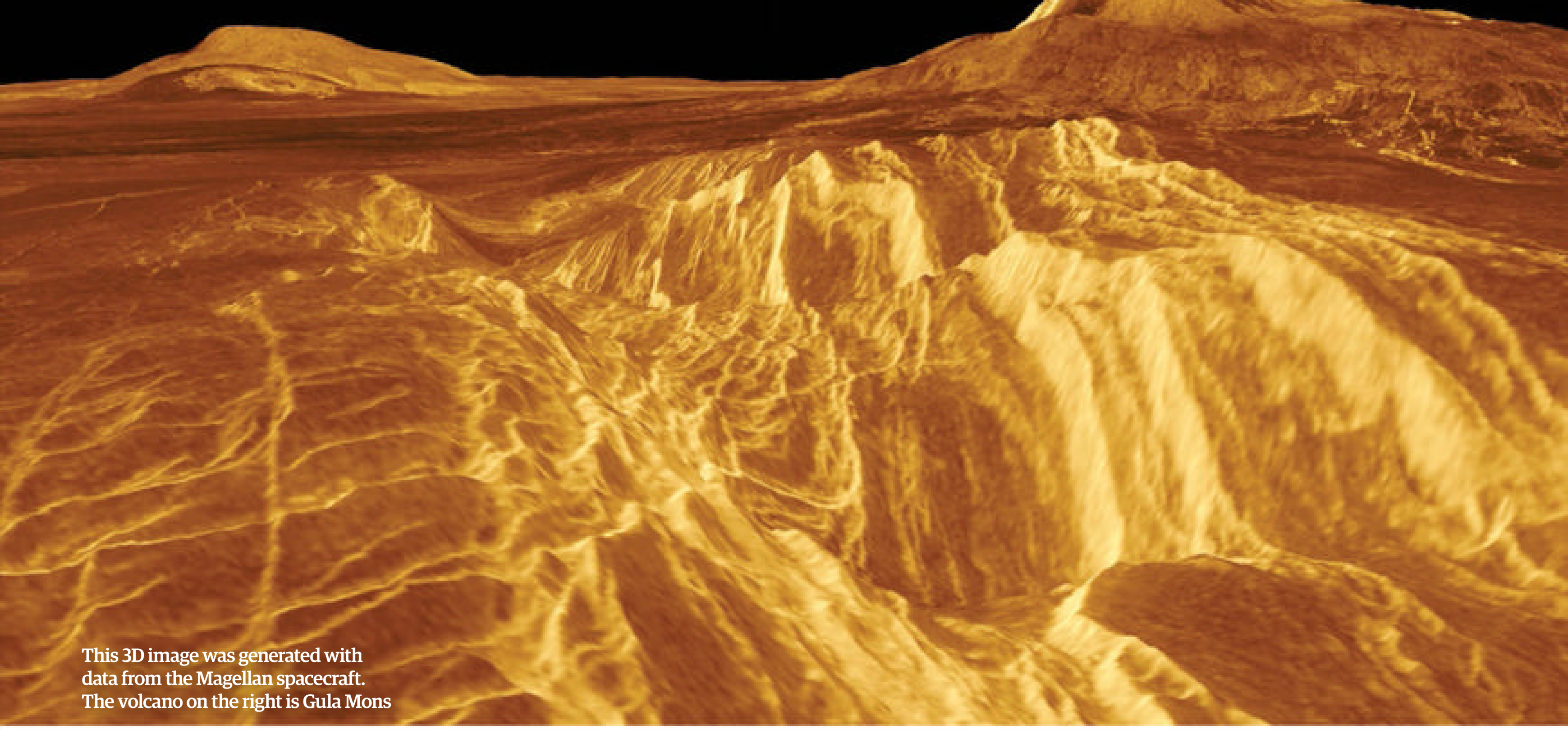
Everything that we've learned about Venus's surface is from radar, because the atmospheric pressure is too great for a probe to survive longer than an hour. But Magellan has mapped most of the surface, and showed that Venus has a lot of interesting surface features. It has a relatively flat surface, with about 13 kilometres (eight miles) between the lowest point and the highest point. Most of them fall into one of three categories: highlands, deposition plains and lowlands. There are also some mountain ranges, with the highest one, Maxwell Montes at 11 kilometres (6.8 miles). The highlands comprise about ten per cent of the planet's overall surface area, and there are two main 'continents's – Ishtar Terra and Aphrodite Terra. The deposition plains (formed from lava flows) cover over half of the surface, and the rest of the planet is lowlands.

Venus has a relatively smooth surface compared to the other terrestrial planets, but this is probably because the atmosphere burns up smaller meteors before they can reach the surface. There are still about 900 impact craters, and few of them are smaller than 30 kilometres (19 miles). The lower number of craters and their apparent youth shows that Venus's surface is young. Of course the planet itself isn't young, so this points to major events that have remapped the surface entirely. Scientists theorise that these events happened about 300 million years ago, and probably were due to low-viscosity lava flows that lasted for millions of years. One theory is that decaying radioactive elements heated up in the mantle, eventually forcing their way to the surface. The lava flows covered most of the planet, and then the mantle cooled down periodically. Venus doesn't have tectonic plates like Earth, but has a lot of features typically associated with plate tectonics.

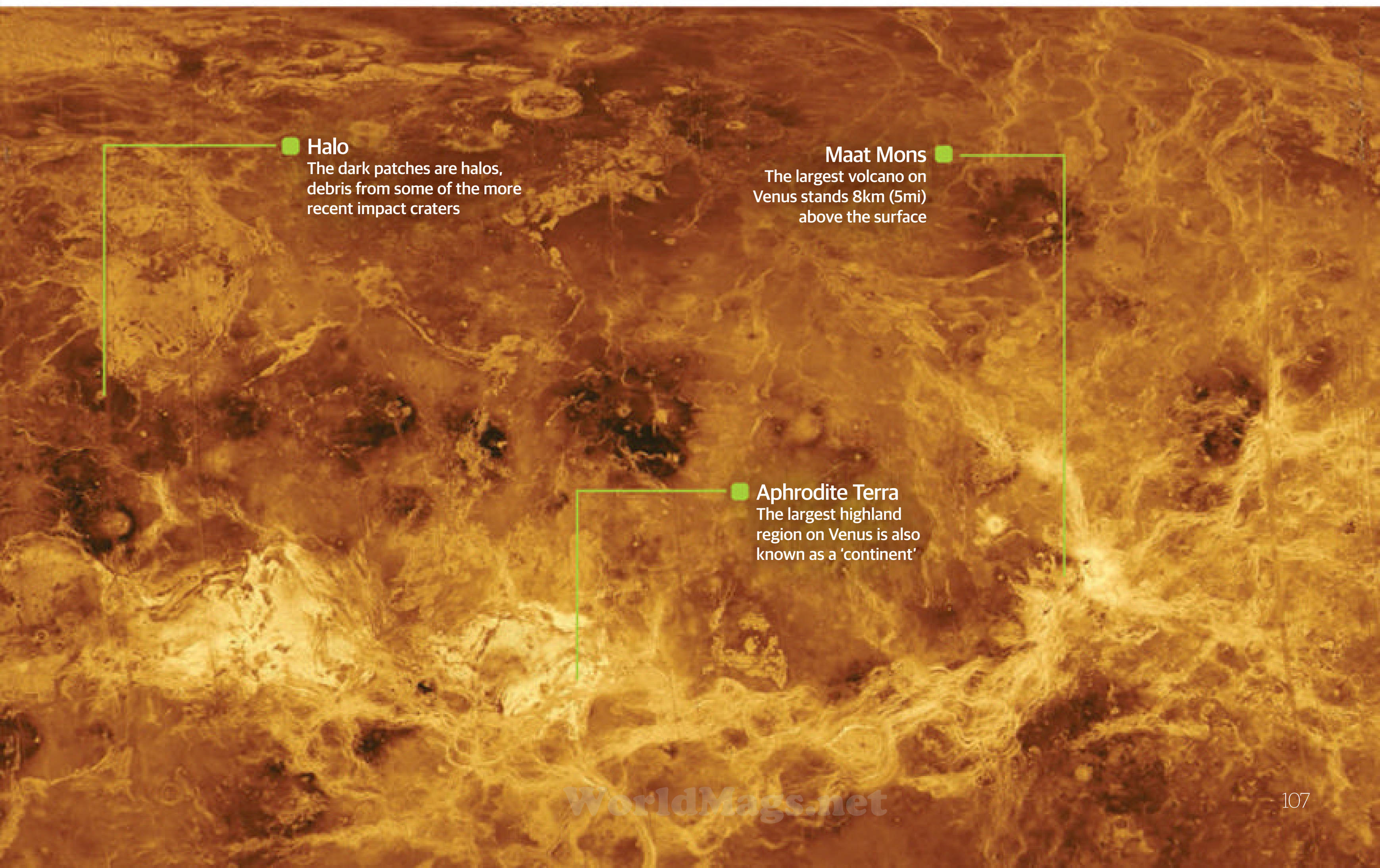
The most prominent features on Venus are due to volcanism. These include about 150 large shield volcanoes, many of which are called pancake domes because they're very wide and flat. They are usually less than one kilometre (0.6 miles) tall and up to 65 kilometres (40 miles) in diameter, and they're often found in clusters called shield fields. The shape is probably due to both the high pressure atmosphere and thick, silica-rich lava. There are also what may be hundreds of thousands of smaller volcanoes. Venus also has some other volcanic features, including one that has only been seen in one other place in the Solar System – Uranus's moon Miranda. Coronae are ring-shaped structures usually about 300 kilometres (180 miles) across and hundreds of metres above the surface. They probably form when magma pushed up parts of the crust into a dome, but cooled and leaked out as lava. The centre collapsed, resulting in a ring. Venus also has arachnoids, networks of radiating fractures in the crust that resemble a spider's web. They may form the same way as novas, ridges and trenches that come from magma pushing through the surface, but astronomers don't know for sure.

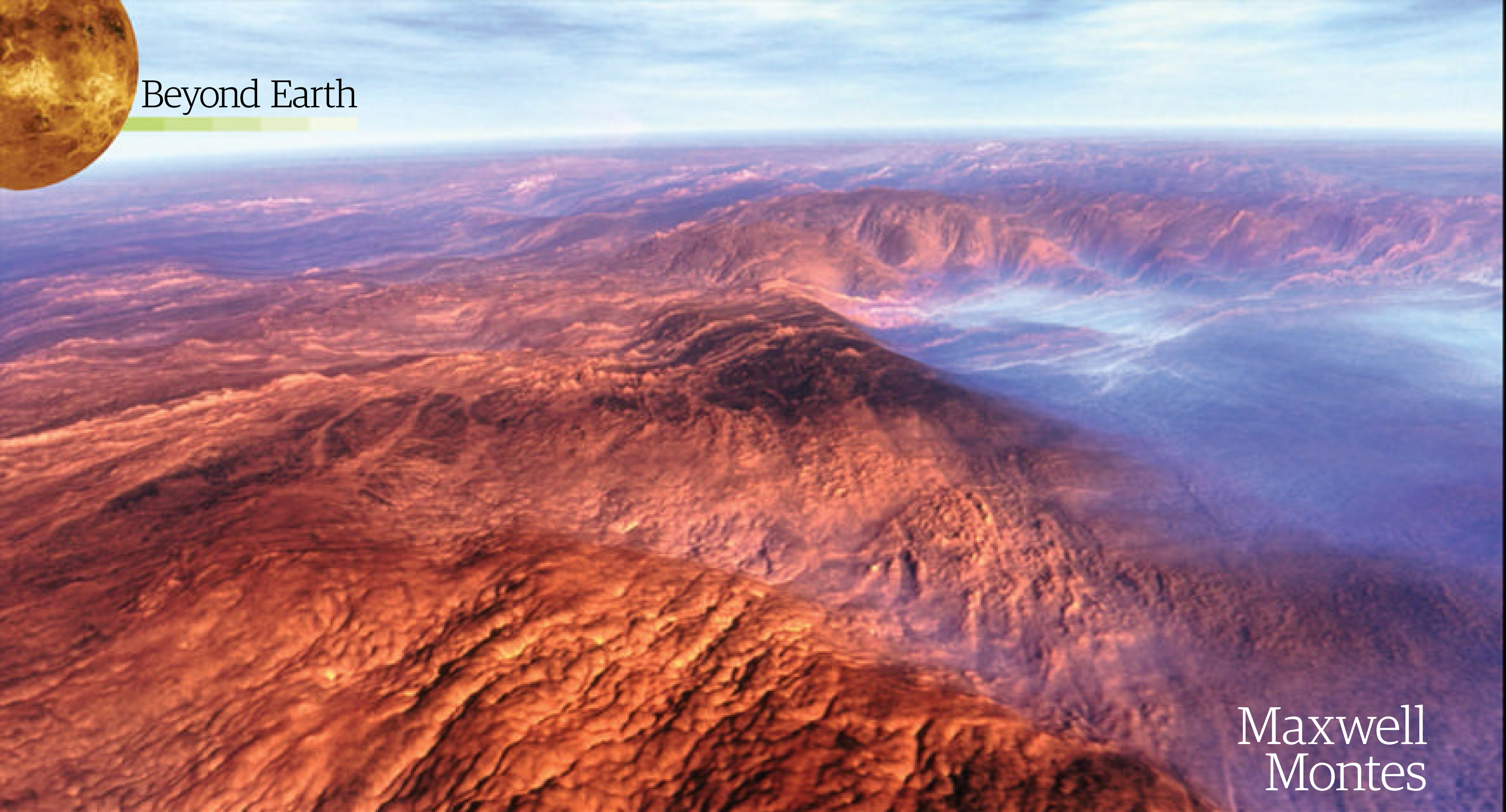


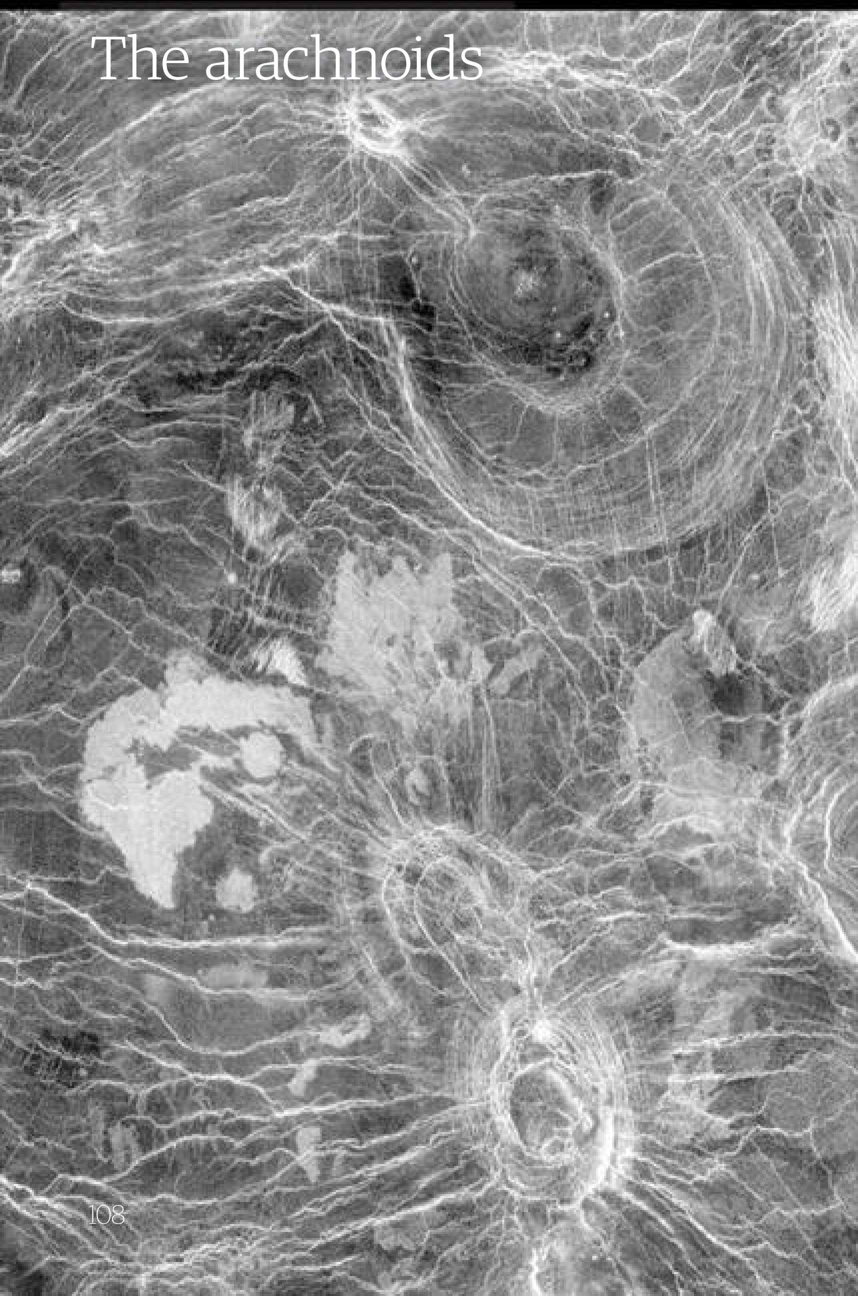
“Venus is smooth because the atmosphere burns up smaller meteors before they can reach the surface”



This 3D image was generated with data from the Magellan spacecraft. The volcano on the right is Gula Mons







Mountains, volcanoes and craters

The extraordinary features that dominate the surface of Venus

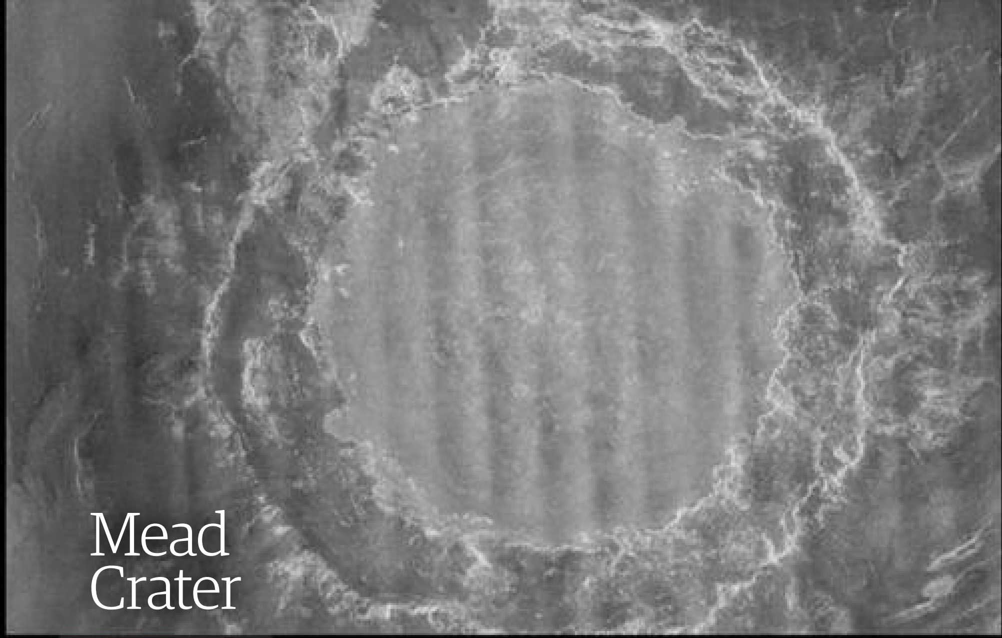
Maxwell Montes
Maxwell Montes is the tallest mountain range on Venus, reaching 11 kilometres (6.8 miles) above the mean planetary radius. By comparison, the tallest mountain on Earth, Mount Everest, is 8.8 kilometres (5.5 miles) tall. Although this is a computer-generated image, it was formed using data from the Magellan spacecraft.

The arachnoids
Spider-web like formations crawl across the surface of Venus. Arachnoids are formations of unknown origin that look like concentric circles of cracked crust. They can cover as much as 200 kilometres (124 miles).

Mead Crater
A crater almost as big as the largest crater on Earth. Mead Crater, named after anthropologist Margaret Mead, is the largest impact crater on Venus's surface. It's 280 kilometres (170 miles) wide, just 20 kilometres shy of Earth's widest crater Vredfort. It has an inner and outer ring and is located north of Aphrodite Terra.

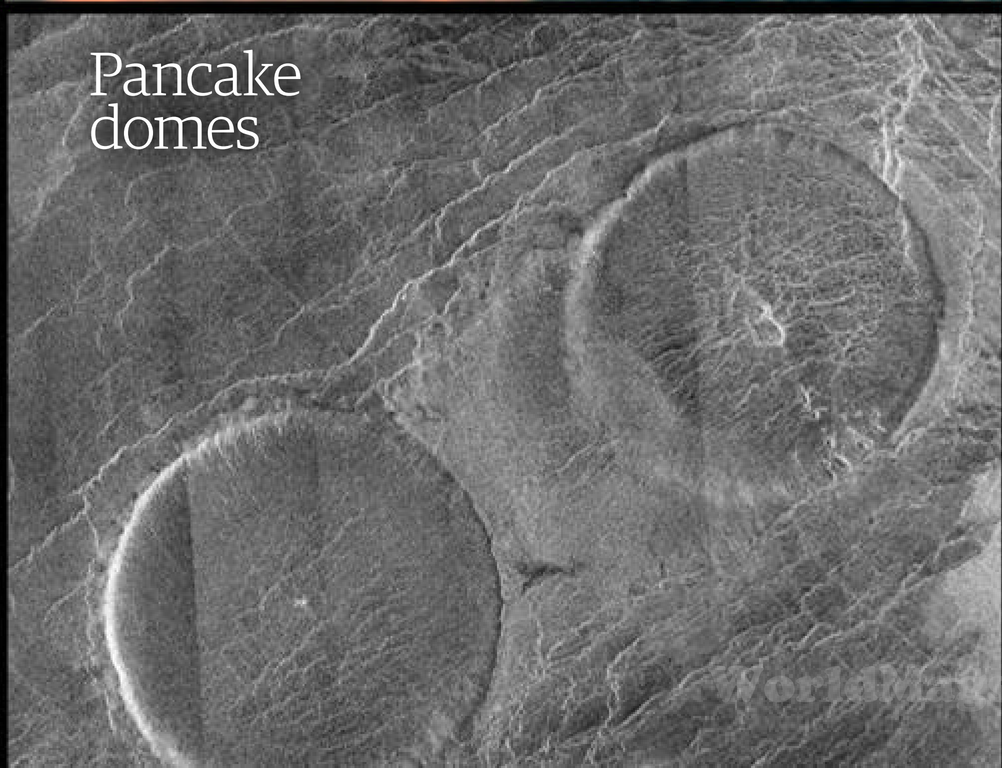
Maat Mons
Maat Mons is eight kilometres (five miles) above the surface of Venus, and is its highest volcano. It has a huge caldera, or cauldron-shaped collapse, about 28 kilometres (17 miles) by 31 kilometres (19 miles). The caldera contains five smaller craters as a result of the volcano's collapse. Magellan revealed relatively recent volcanic activity in the area.

Pancake domes
Venus is known for unique volcanic formations called pancake domes. These pancake dome volcanoes are located in the Eistla region of Venus. They're about 65 kilometres (40 miles) in diameter with tops that are less than one kilometre (0.6 mile) in height. These volcanoes are formed when viscous lava is extruded under Venus's high-pressure atmosphere.



Mead Crater

Maat Mons



Pancake domes

Venus in numbers

Fantastic figures and surprising statistics about Venus

243 DAYS

It takes 243 days for Venus to rotate but only 225 days for it to orbit the Sun

38 million km

The closest Venus gets to Earth, making it our nearest planetary neighbour

92x greater

The pressure on the surface of Venus is 92 times that on Earth

62%

Percentage of the 42 missions to Venus that have been successful

450°c

The maximum temperature on Venus

1,000

There are more than 1,000 volcanoes or volcanic craters on Venus

650km

Venus is just 650km less than Earth in diameter

All About... MARS

The fourth planet from the Sun and the seventh largest, the red and varied landscape of this once Earth-like planet has fascinated humanity since we first viewed it in the night sky. We explore just why this planet holds such allure

Because it appears red due to the rust in its atmosphere, Mars has long been called The Red Planet. Its 'bloody' appearance is also why it was named after the Roman god of war. But that potentially scary appearance hasn't kept us from wanting to learn more about it. Mars formed about 4.6 billion years ago, along with the other planets in the Solar System. After the initial formation, Mars was bombarded at length by meteors, which caused its heavily cratered appearance. As the planet separated into layers, molten rock in the mantle pushed through the crust, resulting in volcanic activity. The activity released a lot of heat from the core, which led it to cool down very quickly. Atmospheric water likely froze, causing flooding, but the lack of atmospheric pressure meant that water was swirled away by solar winds. Eventually Mars settled down into the dry, dusty planet we've been watching since ancient times.

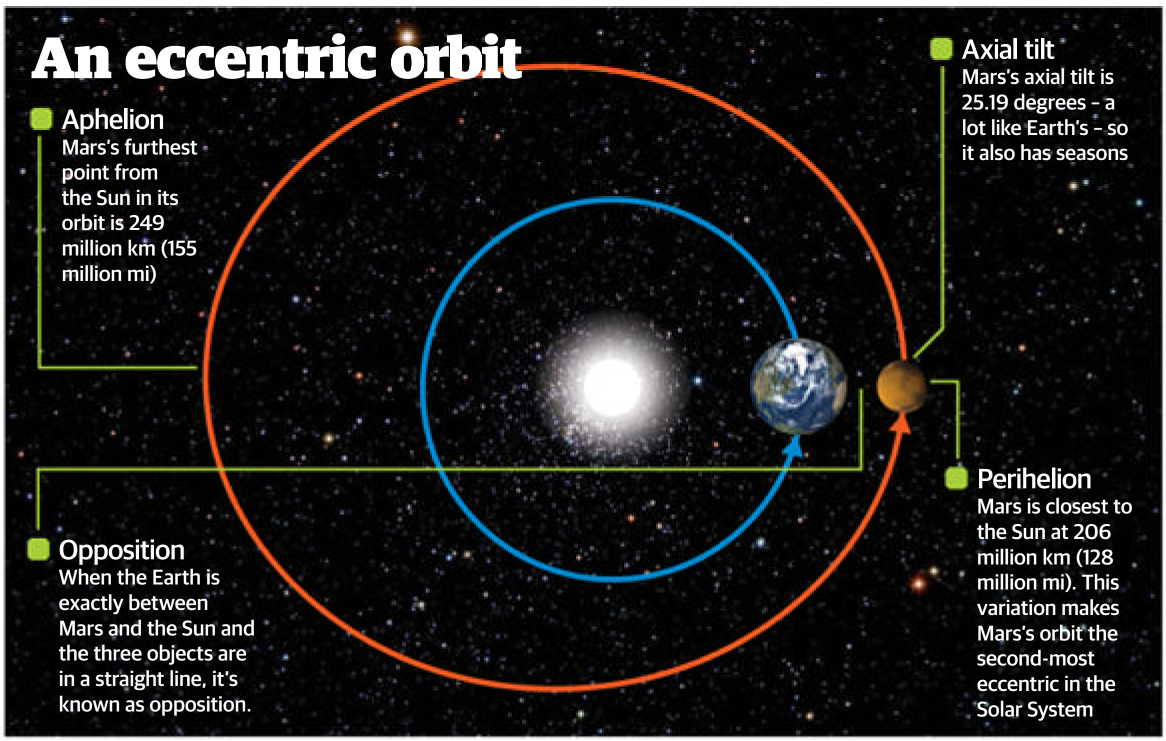
We can easily see Mars from Earth without a telescope, and it's actually easier to see when it's further away from the Earth in its orbit because our atmosphere gets in the way. We've sent lots of probes to the planet, including the recent addition of NASA's Curiosity rover. So far we've discovered that Mars is so much like the Earth, but also so very different. It is a terrestrial planet and has almost identical geographical features and a similar axial tilt (which results in seasons). It also has basically no atmosphere, no liquid water and wildly fluctuating temperatures on the surface. If there are any Martians lurking around, they have to be a hardy group - and so far they've eluded detection. Mars is red, but not all red. Although we can see the planet, we can't actually see any of its features. We do, however, see albedo features, areas of light and dark. While most of the planet is red there are also bright white areas at the poles, some upland areas, and also in the form of ice clouds. The darker spots are places where the intense wind has removed the dust to expose basaltic volcanic rock.

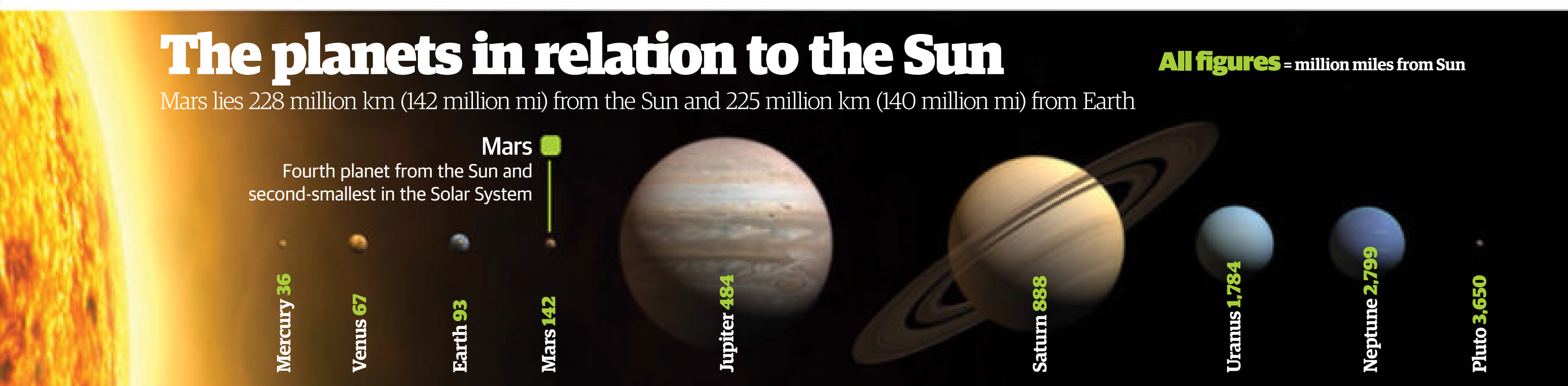
Mars is the fourth planet from the Sun in the Solar System, right between the Earth and Jupiter. Size-wise it is the second-smallest planet behind Mercury. Despite all of the Earth comparisons, it's about half the diameter of Earth, and much less dense. In fact, its mass is about 11 per cent that of Earth's and its volume is about 15 per cent. But because there are no oceans on Mars, it has the same amount of dry land as the Earth does.

The planet's average distance from the Sun is about 228 million kilometres (142 million miles). It takes 687 Earth days to orbit the Sun, but Mars has a very eccentric elliptical orbit. Its eccentricity is 0.09, which is the second-most eccentric in the Solar System behind Mercury (the Earth has an orbital eccentricity of 0.0167, which is almost a circle). But we believe that Mars once had a much rounder orbit - it has changed due to gravitational influences from the Sun and other planets. Rotation-wise, a Martian day is just a bit longer than an Earth day at 24 hours, 39 minutes and 35 seconds. Mars is also tilted 25.19 degrees, close to the Earth's axial tilt of 23.44 degrees. That means depending on where the planet is in its orbit around the Sun, different hemispheres will be exposed to more light - better known as seasons. They aren't seasons like we know them, which are fairly equal in length on Earth. On Mars, spring is seven months long, for example, while winter is only four. The seasons are longer because the year is longer - Mars is further away from the Sun than the Earth - but they vary because of the eccentricity of Mars's orbit.

Mars also has two natural satellites, or moons - Phobos and Deimos. Both are potato-shaped and may have been asteroids that got trapped by Mars's gravitational pull or they could have formed from material ejected from Mars during impact. The planet might also have other tiny satellites that have yet to be discovered.

"Because there are no oceans on Mars, it has the same amount of dry land as the Earth does"



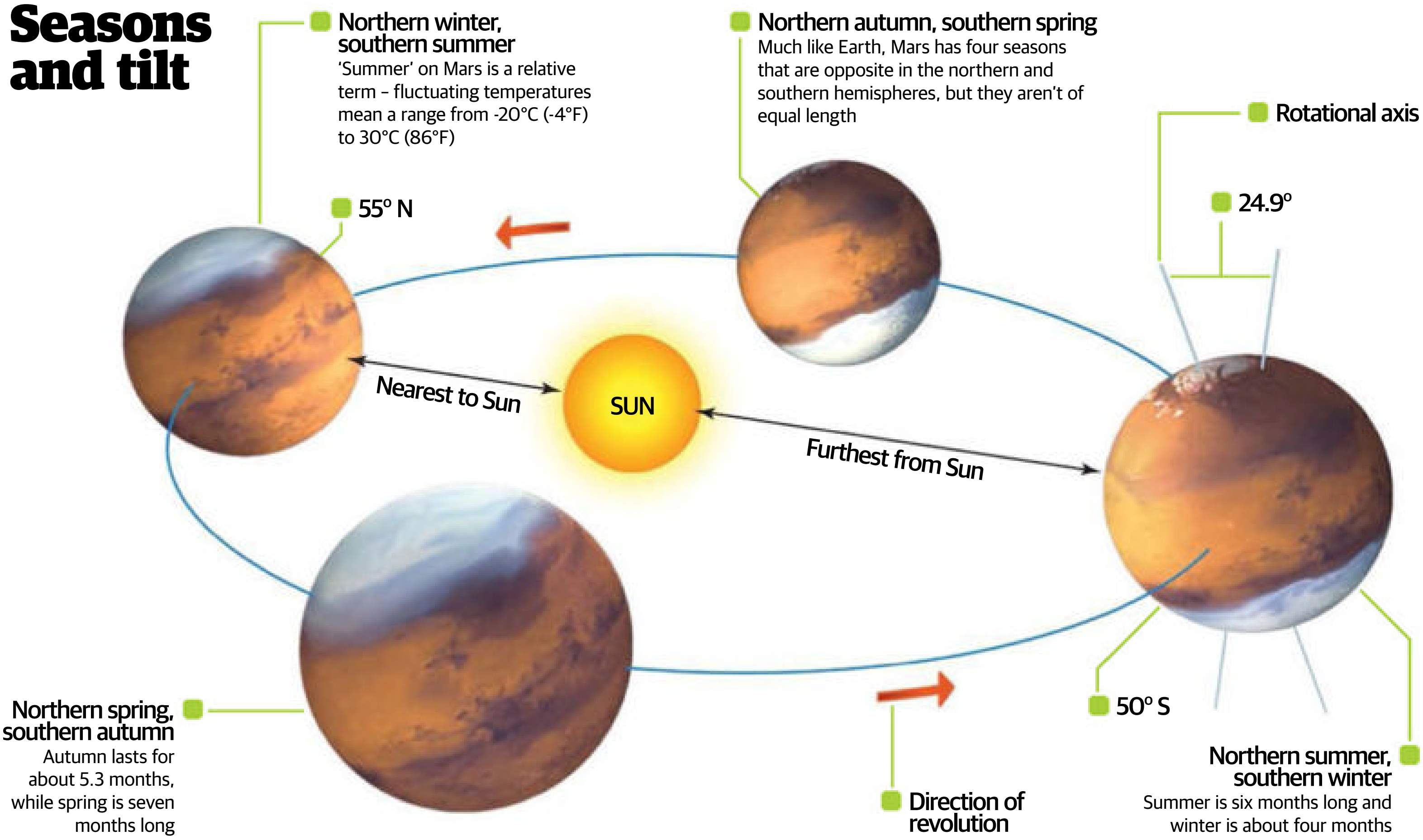


Over the years science fiction has often portrayed Mars as a sister planet to Earth and although there are many key differences – the small matter of life, for example – a true understanding can often be reached by making the right comparisons. NASA has referred to Earth as 'one of the best comparative laboratories' and the study of Mars can provide scientists with a control set for studying the potential for life beyond our world.

As mentioned, the chief of these differences is the size of the planet: Mars is a smaller world with 53 per cent the diameter and just 11 per cent the mass of Earth. The surface gravity on the Red Planet is 38 per cent that of Earth's, meaning that a human who can jump one metre (3.3 feet) on Earth could jump 2.6 metres (about nine feet) on Mars. As well as the similar land surface area the atmospheric chemistry is relatively similar especially when Earth and Mars are compared to other planets in the Solar System. Both planets have large polar ice caps made primarily of water ice, according to current thinking. Other similarities include a similar tilt in their rotational axis, which causes strong seasonal variability. ■

Mars is around half the size of Earth and has just 11 per cent of its mass

Seasons and tilt



The moons of Mars

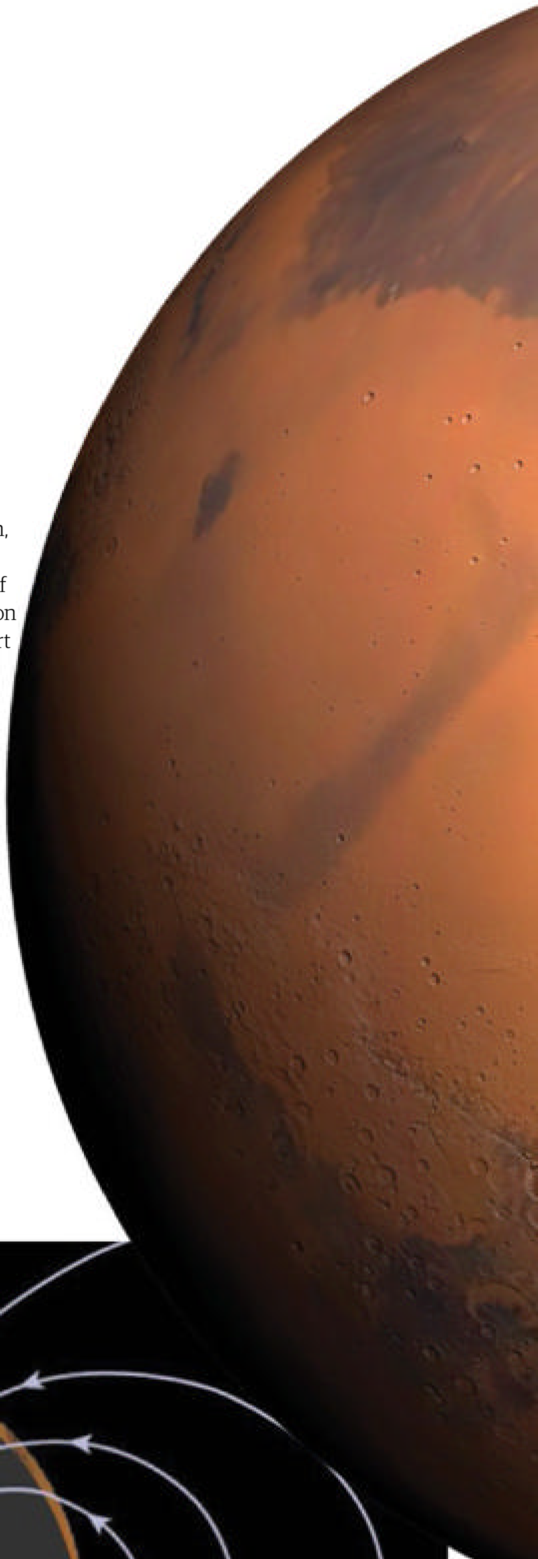
Phobos

Phobos is the bigger of Mars's two satellites, and orbits the closest. In fact, it orbits closer to its planet than any other satellite in the Solar System. The distance from the moon to the planet is about 6,000km (3,700 mi) from the surface. Phobos has a radius of about 11km (seven mi) and is irregularly shaped and non-spherical. Its biggest feature is a large impact crater named Stickney, which has a diameter of about 9km (5.6 mi).

Deimos

Deimos is much farther from Mars than Phobos at around 23,400km (14,600 mi) away. It's also significantly smaller, with a radius of around 6km (four mi), and takes much longer to orbit Mars at 30.4 hours. Deimos, like Phobos, is not at all spherical. It has a very porous surface, and also features large craters relative to its size, with the two largest being Swift and Voltaire. Both craters are believed to be between 1 and 3km (0.6 and 1.9 mi) in diameter.

Mars inside and out



Its make-up may resemble Earth's, but Mars is a very different planet

Mars is a terrestrial, or rocky, planet – just like Earth. It also has a differentiated internal structure, meaning that there's an outer crust, a mantle and a core. However, that structure isn't exactly like the Earth's.

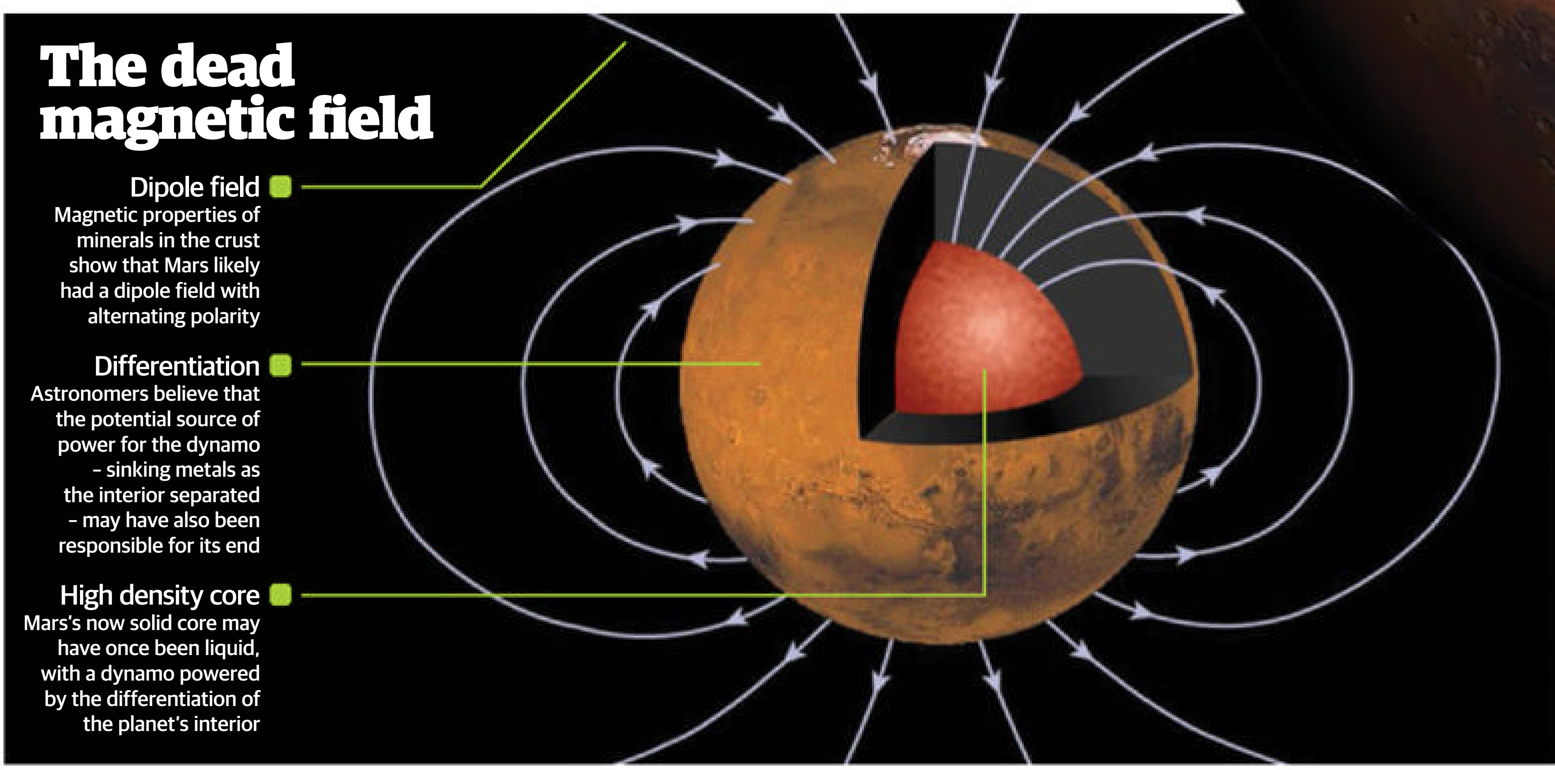
At the centre of the planet, Mars's core is believed to be between around 3,000 and 4,000 kilometres (1,850 and 2,500 miles) in diameter. It's mostly made up of iron, with nickel and traces of other elements, such as sulphur. Scientists believe that the core is mostly solid but may also contain a fluid layer. There is no magnetic field generated at the core, but Mars may have had a magnetic field in the past. There are currently areas of magnetisation at different places on the planet's surface. The differentiation process, in which heavier metals such as iron sunk through to the core while Mars was forming, may be responsible for the end of the Red Planet's magnetic field.

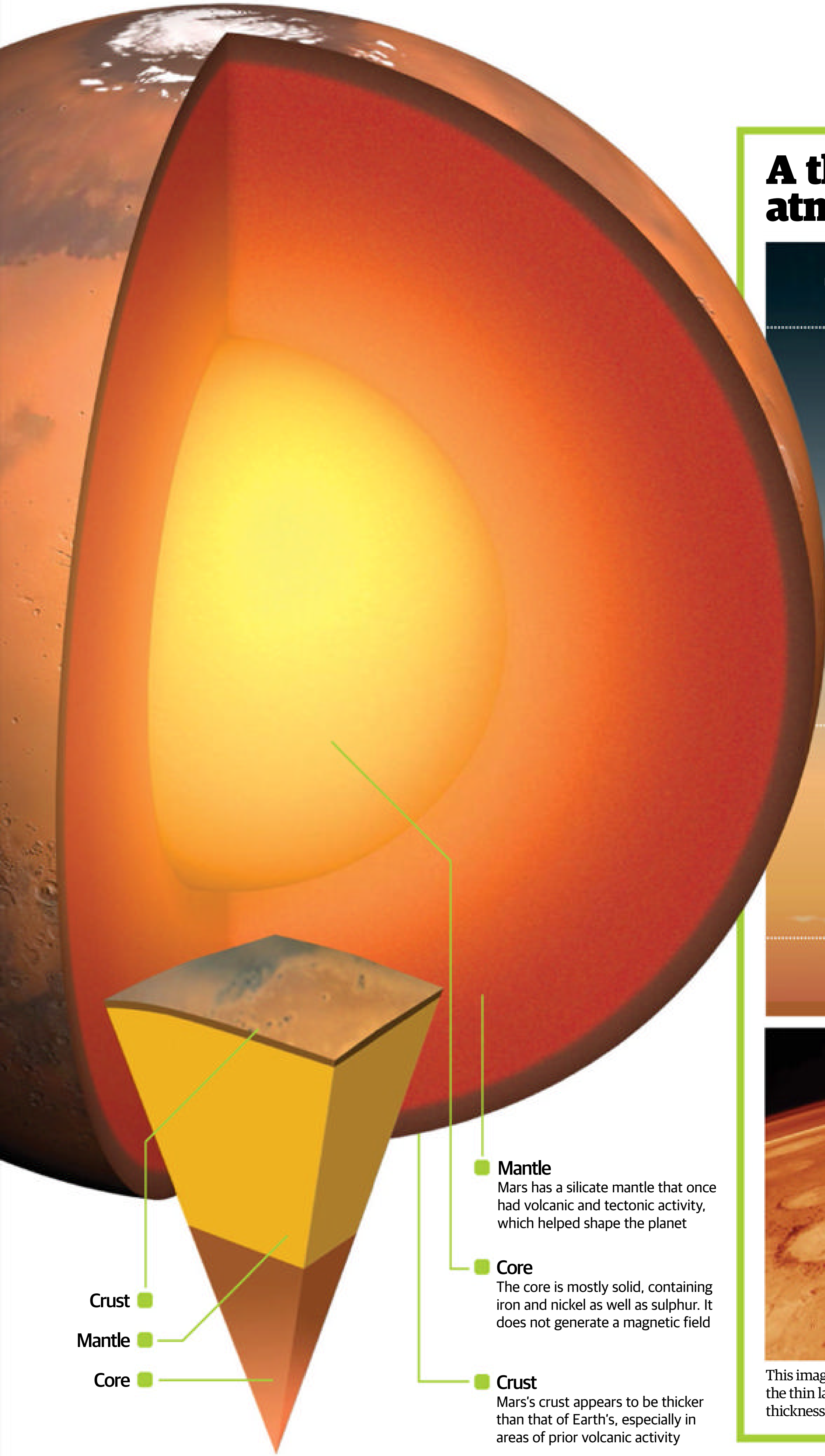
Atop the core lies Mars's silicate mantle, which is between 1,300 and 1,800 kilometres (800 and 1,100 miles) thick. Volcanic activity on the planet's surface originated here, resulting in the huge volcanoes, lava flows and other features that can be found on Mars's surface – however, the most recent volcanic activity likely took place about 2 million years ago. That may not be particularly recent by our standards, but it's fairly recent when it comes to Mars's history. These were lava flows, however; the volcanoes appear to be extinct.

Finally, there's the crust, which is about 25 to 80 kilometres (16 to 50 miles) thick. It contains oxygen, silicon, iron, calcium and other metals. The high concentrations of iron and oxygen result in rust – iron oxide – which is responsible in part for the red appearance of Mars. At its thickest the crust is more than twice as thick as the Earth's crust. The surface is covered with regolith in many places – a loose conglomerate of broken rocks, dirt and dust.

There isn't much atmosphere – the solar wind strips away molecules and carries them out into space. It is about 95 per cent carbon dioxide, three per cent nitrogen, two per cent argon with trace gases as well.

"The solar wind strips away molecules and carries them out into space"



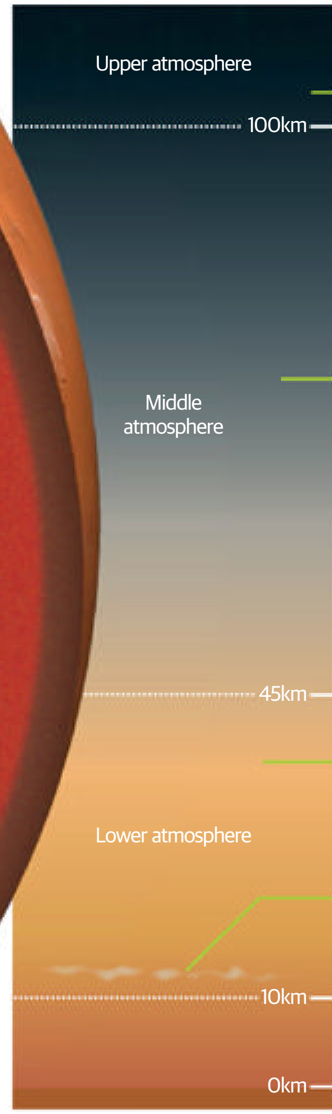


Mantle
Mars has a silicate mantle that once had volcanic and tectonic activity, which helped shape the planet

Core
The core is mostly solid, containing iron and nickel as well as sulphur. It does not generate a magnetic field

Crust
Mars's crust appears to be thicker than that of Earth's, especially in areas of prior volcanic activity

A thin atmosphere

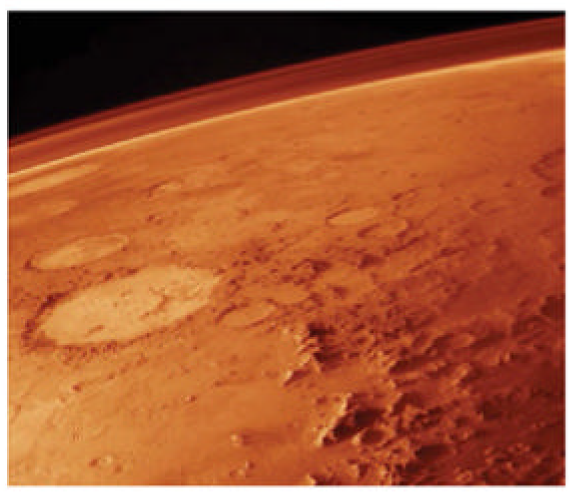


Upper atmosphere
Also known as the thermosphere, this layer is heated by the Sun. The lack of a magnetic field means that the gases separate out into space

Middle atmosphere
In the middle atmosphere, the Martian jet stream swirls the surface dust and gives the sky its orange colour

Lower atmosphere
The atmosphere contains 95 per cent carbon dioxide, three per cent nitrogen, two per cent argon and traces of elements such as methane

Thin ice clouds
Strong winds sweeping off Mars's polar ice caps, along with atmospheric sublimation of carbon dioxide, help create these thin ice clouds



This image, taken by the Viking Orbiter from low orbit, shows the thin layer of Mars's atmosphere – less than one per cent the thickness of Earth's atmosphere

On the surface

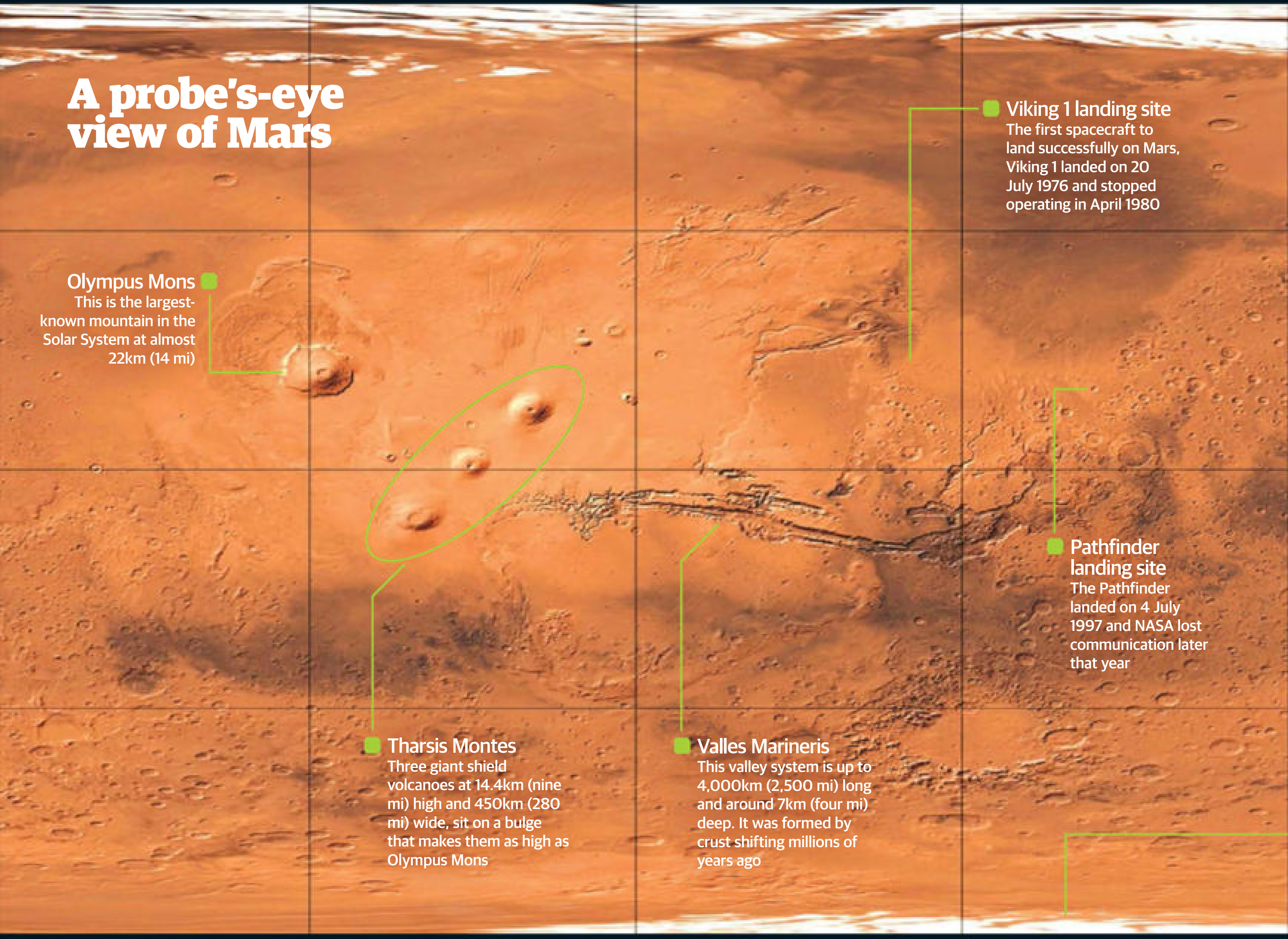
Mars has a lot of geographical similarities with Earth, but there's a reason why we haven't found life there... yet

Thanks to the many images sent back from various probes, we know that Mars has a lot of interesting geographical features. The biggest one is that Mars has incredibly different northern and southern hemispheres. Most of the northern hemisphere is lower in elevation than the southern one (up to six kilometres or four miles lower). It also has far fewer impact craters, and is much smoother and uniform all over. Finally, the crust on the northern hemisphere appears to be much thinner than the southern hemisphere's. While astronomers aren't sure of the reasons behind this dichotomy, it involves the three main forces that have influenced the planet's surface: volcanic activity, tectonics and impacts.

Some of the most striking features on Mars's surface are its mountains - which are all inactive volcanoes. The western edge of the southern hemisphere contains two different areas - the Tharsis bulge and the Elysium volcanic complex - each of which contain several volcanoes. The Tharsis bulge covers about 25 per cent of the planet's surface and lies seven to ten kilometres (four to six miles) above it. This includes Mons Olympus, a shield volcano that is the largest mountain in the Solar System.

Scientists were sure that Mars didn't have plate tectonics like Earth - until last year. That's when we discovered that there are in fact tectonics at work. Not only do features like steep cliffs and the flat walls of canyons show faults at work, but so do the fact that Mars's volcanoes are concentrated in two different areas. The huge valley system known as the Valles Marineris is the deepest in the Solar System and takes up a quarter of the planet's circumference. It's also a plate boundary, with horizontal

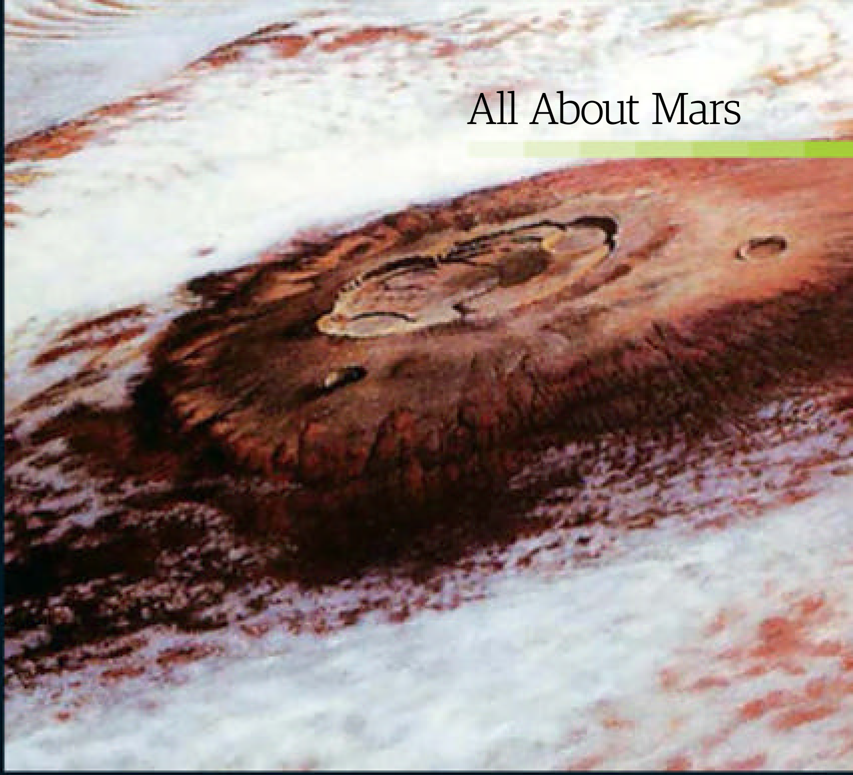
A probe's-eye view of Mars



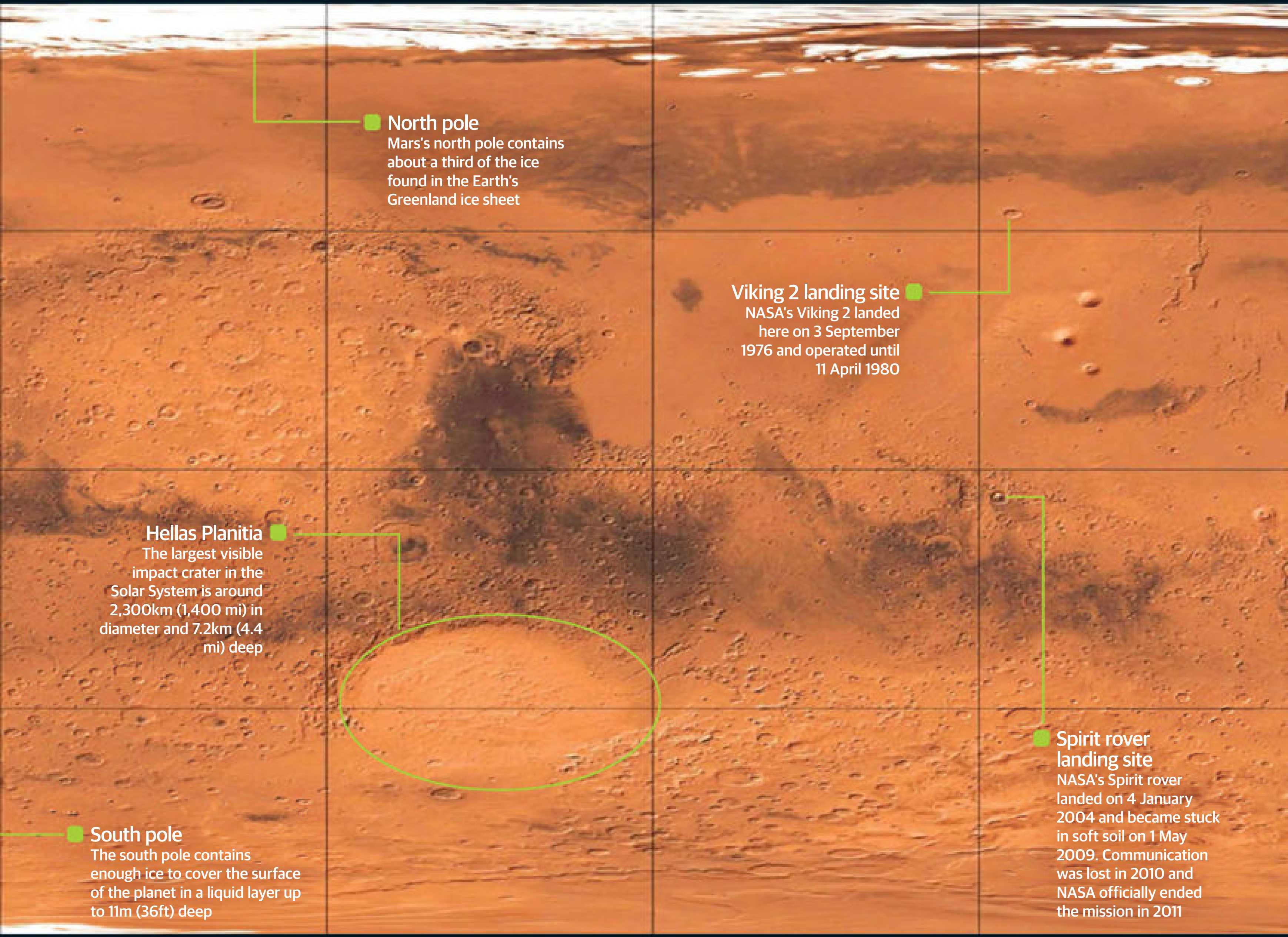
movement along the plates. With just one known fault as opposed to many on Earth, some believe that Mars's tectonic system is much younger.

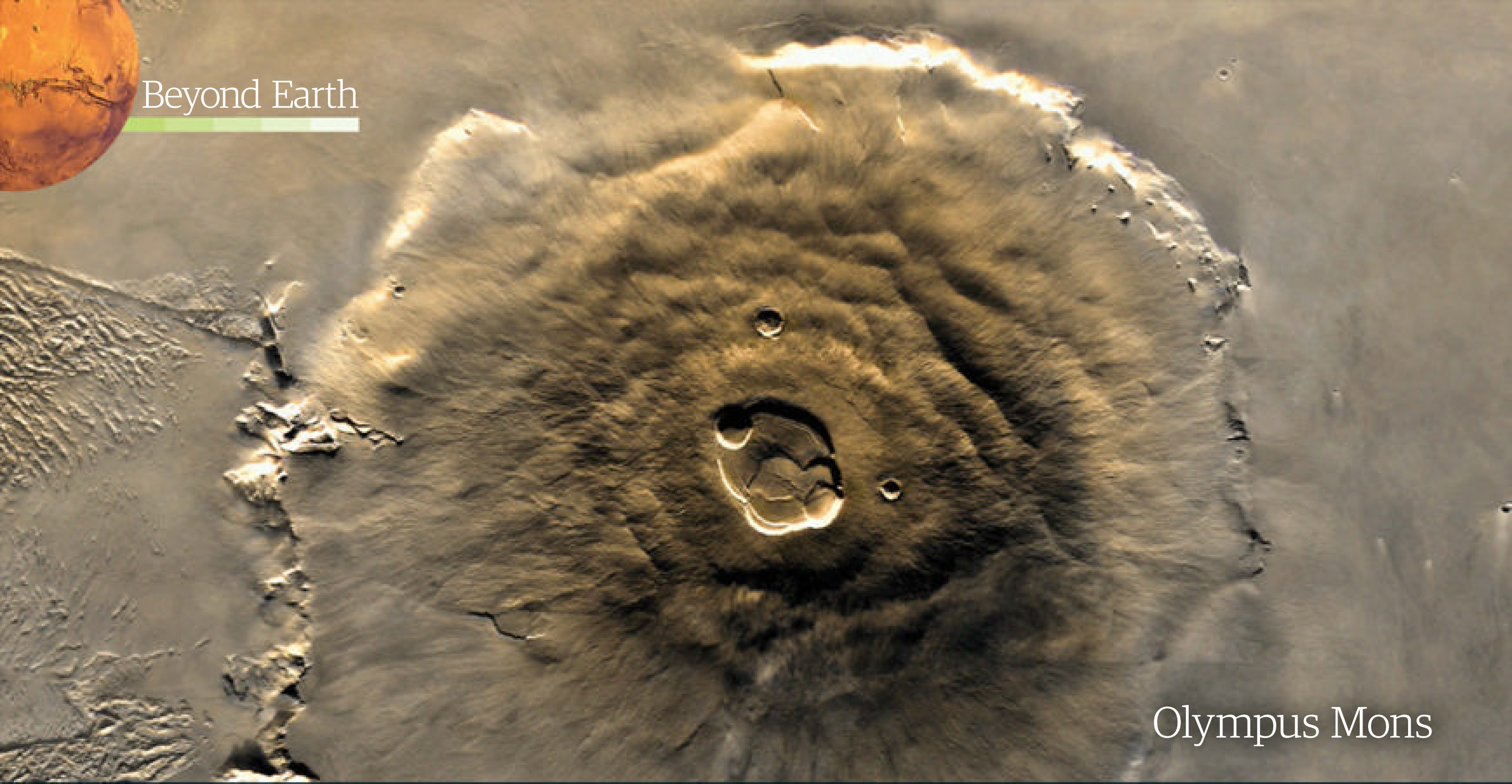
Impact craters and basins are prevalent in Mars's southern hemisphere. The Hellas basin is the largest of these at 1,800 kilometres (1,100 miles) in diameter. The largest basins are believed to date back to a period of heavy bombardment about 3.8 billion years ago. They show evidence of erosion and also contain a lot of regolith, or soil deposits. The smaller craters are younger, and look a lot like the Moon's impact craters. Mars has many different types of craters thanks to erosion, deposits and volcanic activity. They also contain ejecta blankets - flows formed in the soil after an impact melts ice under the planet's surface.

Mars is believed to have ice underneath its surface - and there are also ice caps at the poles, the amount of which changes depending on the seasons. Because Mars has a similar tilt to the Earth, it does have four seasons - they're just longer and of varied lengths. Temperatures can get as low as minus 143 degrees Celsius (minus 225 degrees Fahrenheit) at the ice caps in the winter. The ice beneath the surface freezes and melts depending on the temperature. The atmospheric pressure on Mars is much lower than the Earth's, and it's so thin that there is very little to block the surface from the Sun's heat. There are ice clouds, probably caused when the wind kicks up dust, while one of the Red Planet's biggest weather features is dust storms, which can last up to a month.

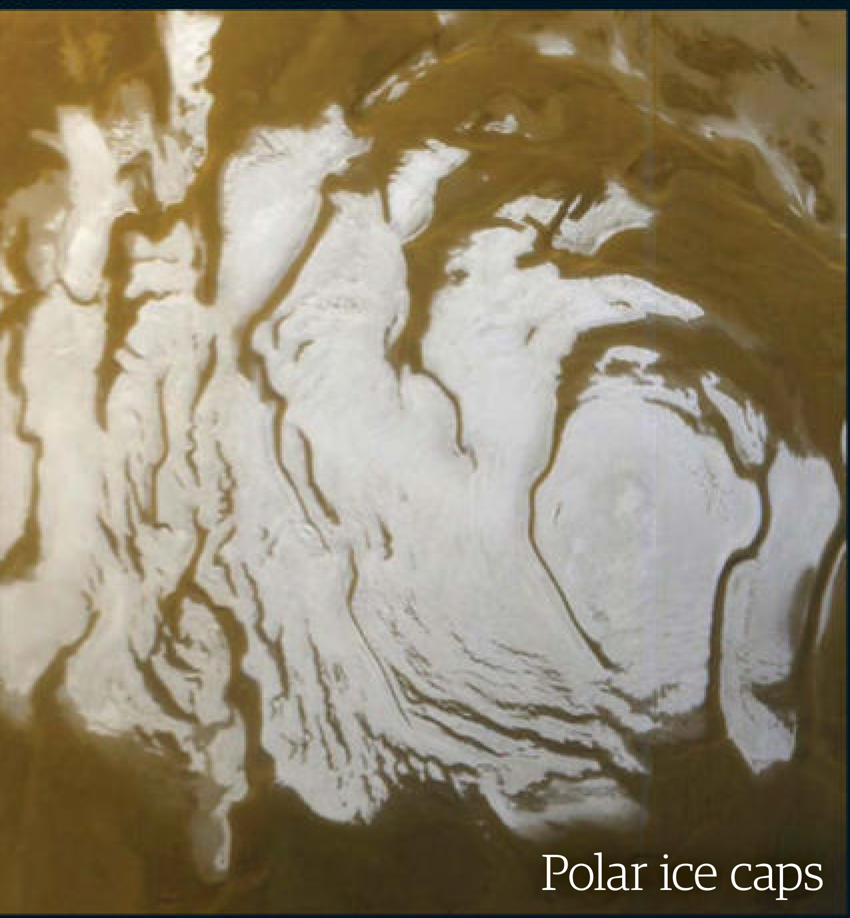


Despite its thin atmosphere, Mars does have a layer of ice-water clouds, although the blanket lies below the planet's tallest volcano, Olympus Mons. A wave cloud due to ripples in the atmosphere is also visible





Olympus Mons



Polar ice caps

Canyons, craters and deserts

Mars is home to some of the largest planetary features in the Solar System

Olympus Mons
Olympus Mons is the tallest known mountain in the Solar System at 22km (14 mi) high. It's more than twice the size of Mount Everest and is an extinct volcano.

Polar ice caps
This polar ice cap on the southern end of Mars grows and wanes each year depending on the season. It is made up of both water ice and dry ice (frozen carbon dioxide).

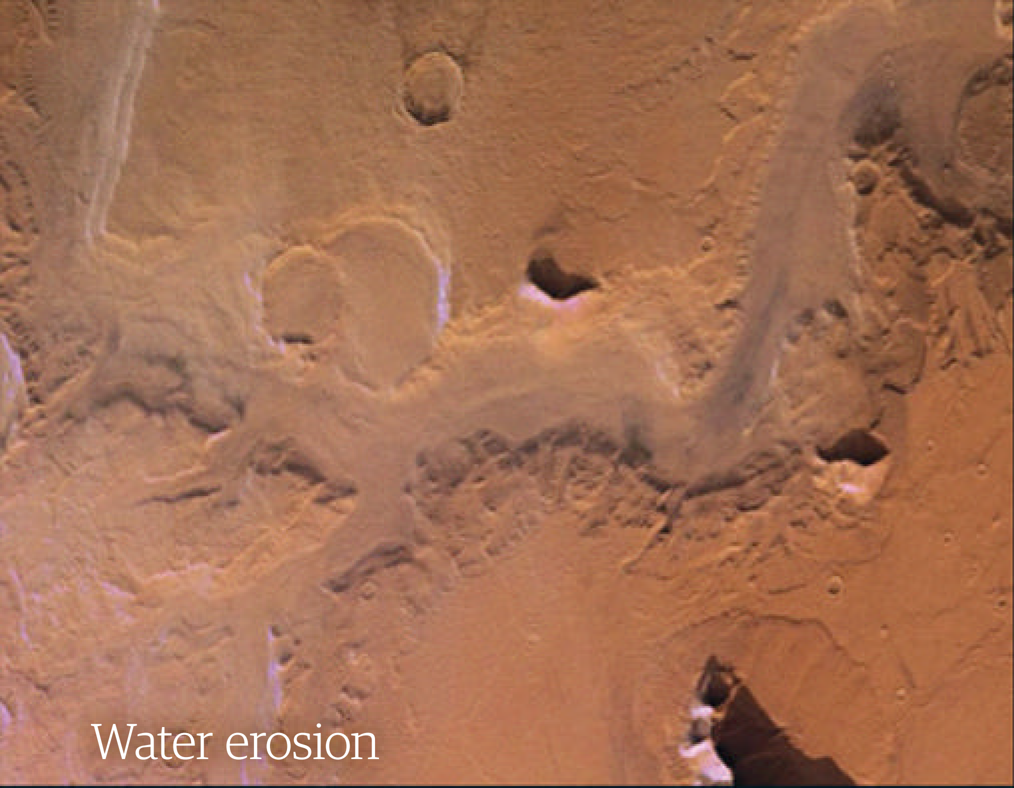
Valles Marineris
Valles Marineris is a system of canyons located along the equator of Mars and covers almost 25 per cent of the planet's circumference. It is around 7km (four mi) deep, 200km (124 mi) wide and 4,000km (2,500 mi) long. On Earth, that would be the approximate distance between New York and Los Angeles.

Water erosion
Reull Vallis is one of the valleys on Mars that look as if they may have been carved out by water movement. Many of these valleys contain grooves on their floors that may be rich in ice.

Sand dunes
Regolith - a mix of soil, sand, dust and broken rocks - has drifted into dunes on Mars's surface. We once thought they were stationary, but observations have shown that the dunes actually move due to prevailing winds.

Hellas Basin
The Hellas Basin is one of the biggest impact craters in the Solar System. At 2,300km (1,400 mi) in diameter, it is wider than the state of Texas.

Valles Marineris


Water erosion


Sand dunes


Hellas Basin

Mars in numbers

Fantastic figures and surprising statistics about the Red Planet

2,300km

The diameter of Mars's Hellas Basin is the same as the diameter of Pluto

2

Mars has two known satellites: the moons of Phobos and Deimos

271 years and 221 days

How long it would take you to get to Mars from Earth if you could drive there in a car at 97km/h (60mph)

14.5

Travelling at a speed of 14.5 miles per second compared to the Earth's 18.5 miles per second, Mars is slower to orbit the Sun

687 Earth days

A year on Mars is 687 Earth days, while a day on Mars is equivalent to 1.026 Earth days

37.5%

Gravity on Mars as a percentage of Earth's. If you could visit, you could jump three times as high as you can on our planet

Exploring Mars

The failure rate for exploring Mars has been high

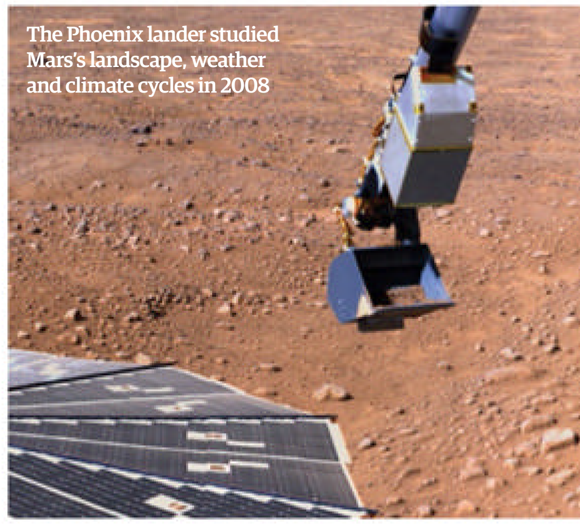
The Soviet Union, not the United States, was the first country to attempt a Mars exploration – but it was unsuccessful. The Mars 1M was just the first of many failed attempts to visit Mars. Since that first attempt in 1960, 43 different spacecraft have tried and only 14 of them completed their missions. Mars 1M had a launch failure, but other probes have been the victims of communication problems, computer malfunctions and even the planet itself. It's been so difficult to get to Mars that some have dubbed the challenge the "Martian curse", and one journalist in the United States jokingly said that there must be a "Galactic Ghoul" hindering our exploration efforts. So why has it proved so difficult to get there?

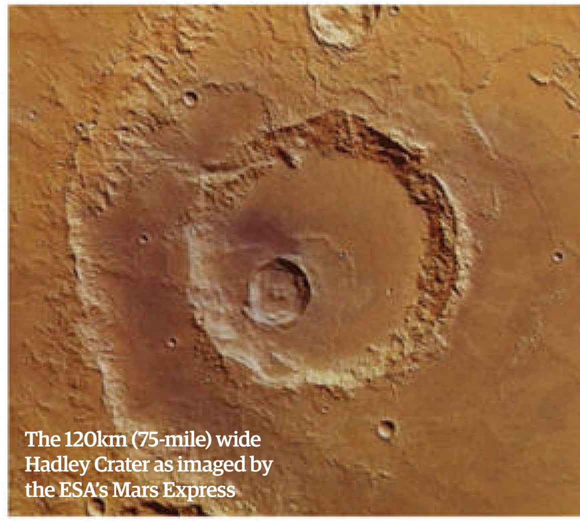

MSL launches atop a Atlas V rocket on 26 November 2011

It takes a spacecraft about seven months on average to travel the 225 million kilometres (140 million miles) to Mars. Once it reaches the planet, if the orbiter has a lander then it must successfully separate and have the lander touch down gracefully on the surface. And Mars can be unpredictable. Things like dust storms and soft soil have impeded landers, for example. But we do have to remember that most of total failures were early in our space exploration history. While there have been some memorable recent failures, including the 1999 Mars Climate Orbiter, which was pure human error. In that case, a contractor used imperial units instead of metric, which caused the probe's rocket to shut down early and send it crashing into the planet.

Currently there are three orbiters around Mars: the Mars Odyssey and Mars Reconnaissance Orbiter, both from NASA, and the European Space Agency's Mars Express. The Opportunity rover has been on the surface since 25 January 2004 and Curiosity recently joined it. Despite the high failure rate, we'll surely continue to explore the Red Planet. It's just too fascinating to keep away.

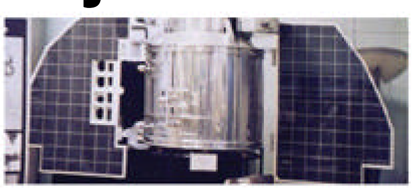
"It takes a spacecraft about seven months to travel the 225 million km to Mars"


The Phoenix lander studied Mars's landscape, weather and climate cycles in 2008

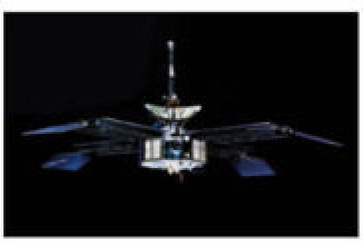

The 120km (75-mile) wide Hadley Crater as imaged by the ESA's Mars Express


The Opportunity rover has been on Mars's surface since 2004

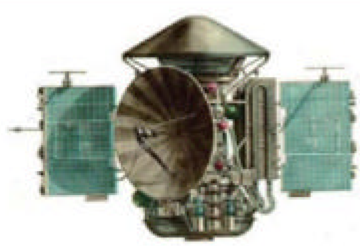
Major missions



Mars 1M
Oct 1960
These Soviet missions were the first in the quest to explore Mars. Mars 1M No 1 experienced a launch failure on 10 October 1960. Mars 1M No 2 met the same fate.



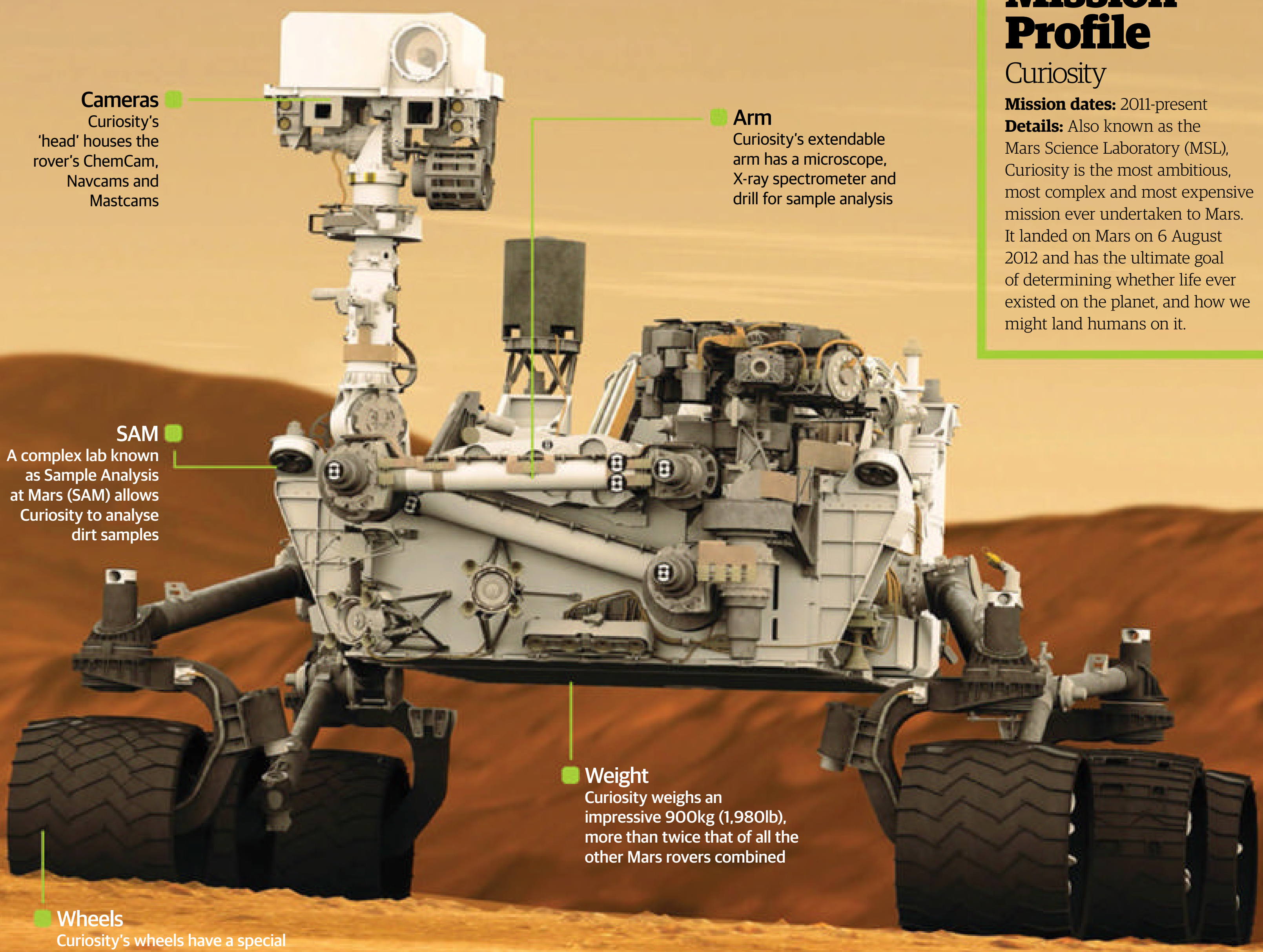
Mariner 4
28 Nov 1964-21 Dec 1967
Mariner 4 performed the first flyby and returned the first colour images of Mars. These were also the first images taken of another planet from deep space.



Mars 2 & 3
19 May 1971-22 Aug 1972
The Soviet-built Mars 2 became the first spacecraft to land – or rather crash – into the surface of the planet. Mars 3 had a soft landing on 2 December 1971.

Viking 1 & 2
20 Aug 1975-13 Nov 1982
Viking 1 landed softly and fully completed its mission. It also held the record for longest Mars mission until the Opportunity rover.

"Despite the high failure rate, we'll surely continue to explore the Red Planet"

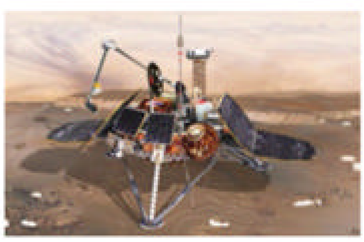


Mission Profile

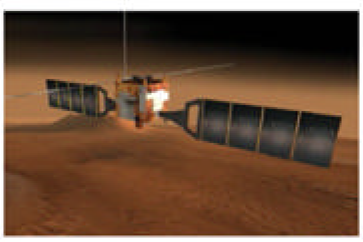
Curiosity

Mission dates: 2011-present

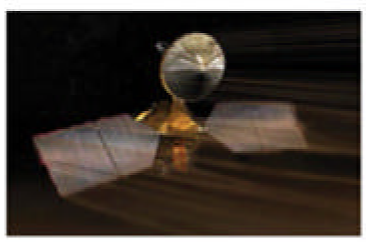
Details: Also known as the Mars Science Laboratory (MSL), Curiosity is the most ambitious, most complex and most expensive mission ever undertaken to Mars. It landed on Mars on 6 August 2012 and has the ultimate goal of determining whether life ever existed on the planet, and how we might land humans on it.



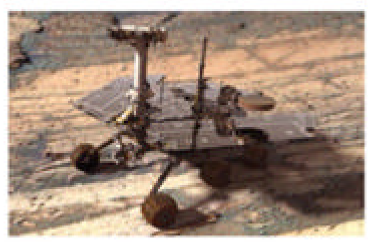
Mars Polar Lander
3 Jan 1999-3 Dec 1999
The Mars Polar Lander was meant to perform soil and climatology studies on Mars, but NASA lost communication with it and it's believed it crashed.



Mars Express Orbiter
2 Jun 2003-present
The ESA's first planetary mission consisted of the Beagle 2 lander and the Mars Express Orbiter, with the latter still operational today.



Beagle 2
2 Jun 2003-19 Dec 2003
The Beagle 2 lander was lost six days before it was due to enter the Martian atmosphere. Attempts were made to contact it, but these ended in failure.



Opportunity
7 Jul 2003-present
Opportunity was a rover launched shortly after its twin, Spirit, by NASA. While Spirit ceased communications in 2010, Opportunity is still going strong.

Mars sample return

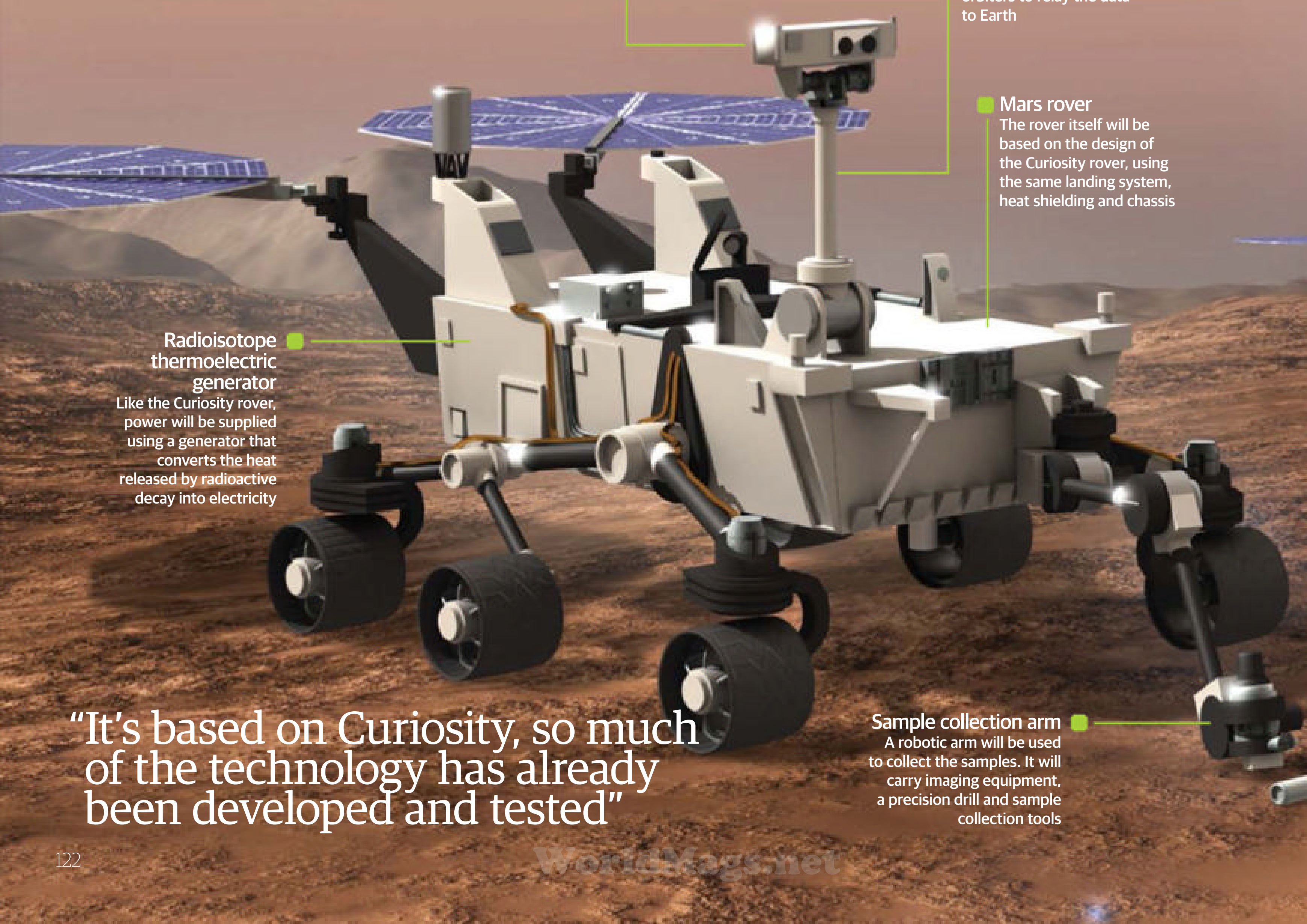
The final step towards bringing Martian rock back to Earth

Orbiter
An orbiting spacecraft will be used to retrieve the samples delivered by the Mars Ascent Vehicle, operated remotely with a time-lag to Earth of around 30 minutes

Atmosphere sample
Atmospheric samples may also be taken, enabling more in-depth study than can be achieved with portable equipment on the planet's surface

Mast
A camera and antenna will allow the rover to store and transmit images, communicating with orbiters to relay the data to Earth

Mars rover
The rover itself will be based on the design of the Curiosity rover, using the same landing system, heat shielding and chassis



Radioisotope thermoelectric generator
Like the Curiosity rover, power will be supplied using a generator that converts the heat released by radioactive decay into electricity

Sample collection arm
A robotic arm will be used to collect the samples. It will carry imaging equipment, a precision drill and sample collection tools

> "It's based on Curiosity, so much of the technology has already been developed and tested"

The Curiosity rover is equipped with an arsenal of technology, but there is a limit as to how much can be achieved remotely. One of the next major steps in the exploration of Mars will be returning samples to Earth for detailed analysis. NASA's proposed Mars sample-return programme aims to do just that.

Several attempts to plan such a mission have failed, like the proposed ExoMars mission for 2018, with cost and technological barriers preventing progress. However, with the continuing success of Curiosity, and the planned Mars 2020 rover mission, new plans for Mars sample-return are underway. The current model involves three separate launches, allowing smaller rockets to be used, and enabling NASA to carefully time each stage of the mission.

The Mars 2020 rover could provide the technology required for the first stage of the project. It will study the history and potential habitability of Mars by analysis of collected rock samples. It's based on Curiosity, so much of the technology has already been developed and tested. What will differ is the scientific payload; it will carry equipment required to retrieve and analyse geological samples, and could be adapted for use in collecting and packaging samples ready for return to Earth.

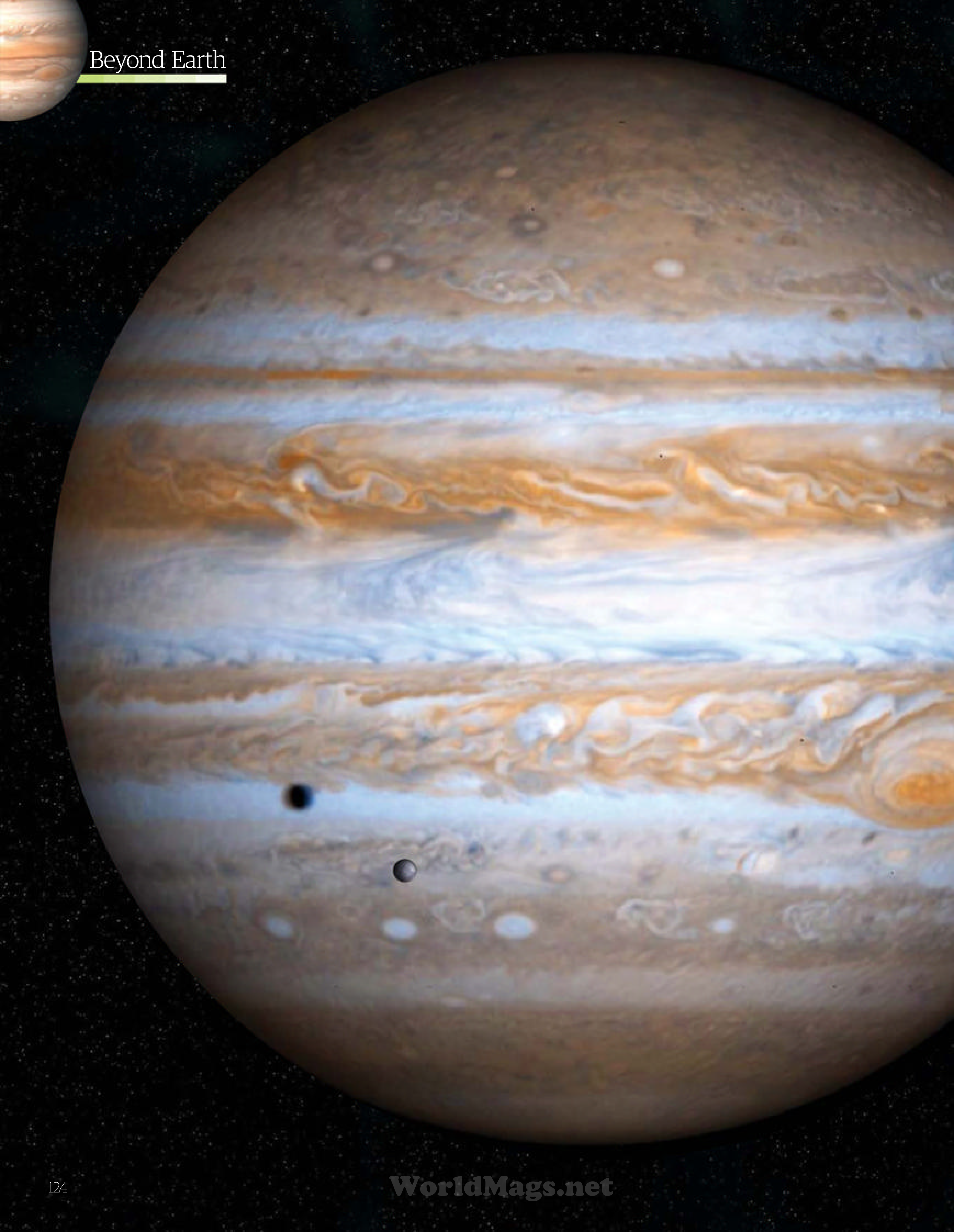
The rover will contain the equipment required to identify the rock samples, including digital imaging software, and using a combination of infrared, ultraviolet and visible light, samples will be selected based on colour and texture. The external surfaces of Martian rocks have been chemically altered by weathering and radiation, so drilling equipment will be used to access the preserved material at the core where traces of biological material might have had the chance to survive intact.

To prevent contamination of the samples and to protect Earth from any unidentified threat, specialist sample containers are in development. A strong, spherical prototype has already been built by ESA to protect up to 11 sample vials, maintaining them at a constant -10 degrees Celsius (14 degrees Fahrenheit). In order to seal the samples inside the container, remote welding technology is in development, which should allow the rover to completely encase the vials in a biologically impenetrable shell.

In order to return the samples to Earth, two more rockets will be launched around four years after the rover. The first of these will contain the Mars Ascent Vehicle, a small rocket being designed to launch the samples into orbit around Mars. The second is a remote-controlled orbiter to find and collect the samples, before returning them to Earth for analysis.

Once inside Earth's orbit, the payload will either be delivered to the ISS and carried home on a spacecraft from there, or it will re-enter the atmosphere directly. Parachutes are often used to slow a craft on re-entry but given the sensitive nature of the samples extra care will be taken to prevent the container from rupture. A vessel has been developed to house the spheres containing the samples and, although it is still in the prototype phase, it has already passed a 400g shock test and a thermal test simulating a parachute failure.

Planning for this ground-breaking project is ongoing, but with the existing technology in such an advanced state already, we could be bringing samples home from Mars as early as 2022. ■



All About... JUPITER

Volatile and violent in nature and named after the Roman king of gods, the largest world in our Solar System has twice the mass of all other planets combined. Discover more about the gas giant that is king of the planets

If you had to choose just one word to describe Jupiter, it would have to be 'big'. It has a diameter of 142,984 kilometres (88,800 miles) at its equator, about 11 times that of Earth's diameter. As the largest planet, with a huge magnetic field and 64 moons and natural satellites, Jupiter could almost be a miniature solar system. Sometimes it's even been referred to as a 'failed star' because it's made of the same gases as the Sun – although it doesn't have anywhere near the mass or temperature to actually be a star. Jupiter would need a mass about 80 times that of its current one, and that's never going to happen. But 'star' is how the ancients thought of it, at least until Galileo noticed that the planet had four prominent moons – Callisto, Europa, Ganymede and Io – that moved around it. It was the first time movement in the Solar System not centred on Earth was discovered, which helped cement Copernicus's theory of a heliocentric – or sun-centred – astronomical model.

Jupiter is the innermost of the four gas giants, along with Saturn, Uranus and Neptune – planets that mainly comprise gas and are also more than ten times that of Earth's mass. The gases get denser as you get closer to the planet's core. Since Jupiter is the largest – the next-largest is Saturn with a diameter of 120,536 kilometres (75,000 miles) – it's not surprising that these gas giants are also called the Jovian planets. Jupiter's mass is 317.8 times that of Earth's and 0.001 times that of the Sun's; sometimes planets outside the Solar System are defined in terms of Jupiter's mass because it's so large. What's amazing is that Jupiter was actually larger when it was first formed – it's been shrinking about two centimetres (0.8 inches) per year due to its heating and cooling process. Jupiter's so massive that its barycentre – or centre of mass with the Sun – lies outside the Sun at 1.068 solar radii above its surface. Although Jupiter is large in diameter and mass, it's not very dense thanks to its gaseousness. Jupiter has a density of 1.33 grams per cubic centimetre, which is about 25 per cent that of Earth's density.

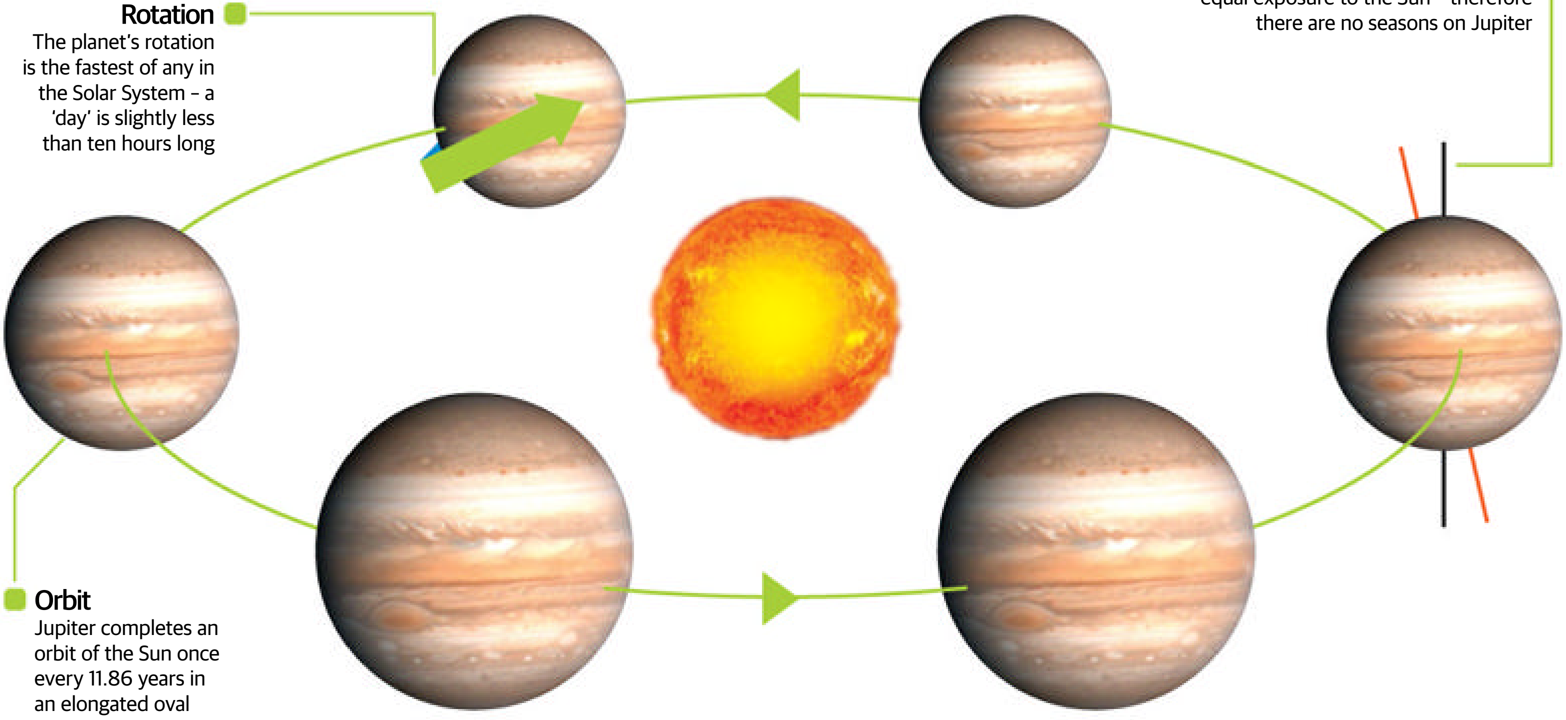
Jupiter is 779 million kilometres (484 million miles) from the Sun on average, completing an orbit once every 11.86 years. This is two-fifths the orbit of Saturn, putting the planets in an orbital resonance of 5:2. It has a very small axial tilt of just 3.13 degrees, so there are no seasons on the planet. It has the fastest rotation of all the planets, taking a quick spin on its axis once every ten hours or so. This gives the planet a bulge around its equator and the shape of an oblate spheroid – it has a larger diameter around its centre than its poles. Because Jupiter is a gas

> "With a huge magnetic field and 64 moons it could almost be a miniature solar system"

The gas giant in orbit

Axial tilt
A tilt of 3.13 degrees means that the northern and southern hemispheres get equal exposure to the Sun – therefore there are no seasons on Jupiter

Rotation
The planet's rotation is the fastest of any in the Solar System – a 'day' is slightly less than ten hours long



Orbit
Jupiter completes an orbit of the Sun once every 11.86 years in an elongated oval

The planets in relation to the Sun

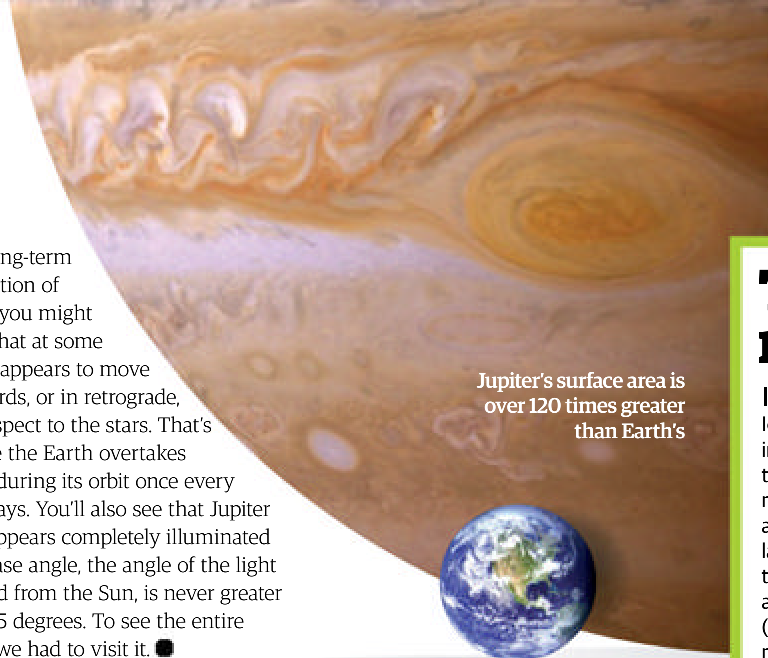
All figures = million miles from Sun

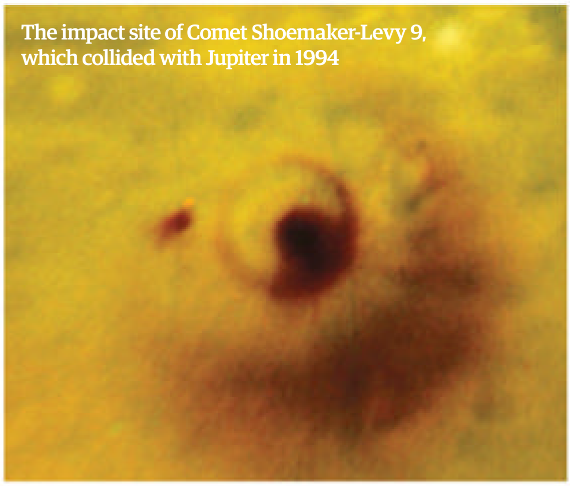
Jupiter lies 779 million km (484 million mi) from the Sun on average, and 629 million km (391 million mi) from Earth

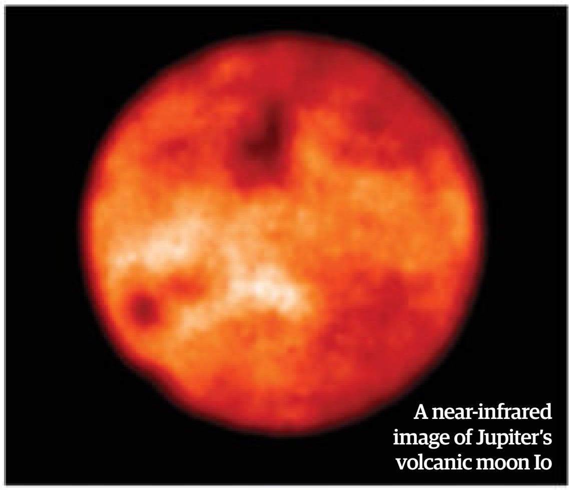
Jupiter
Fifth planet from the Sun and the largest in the Solar System

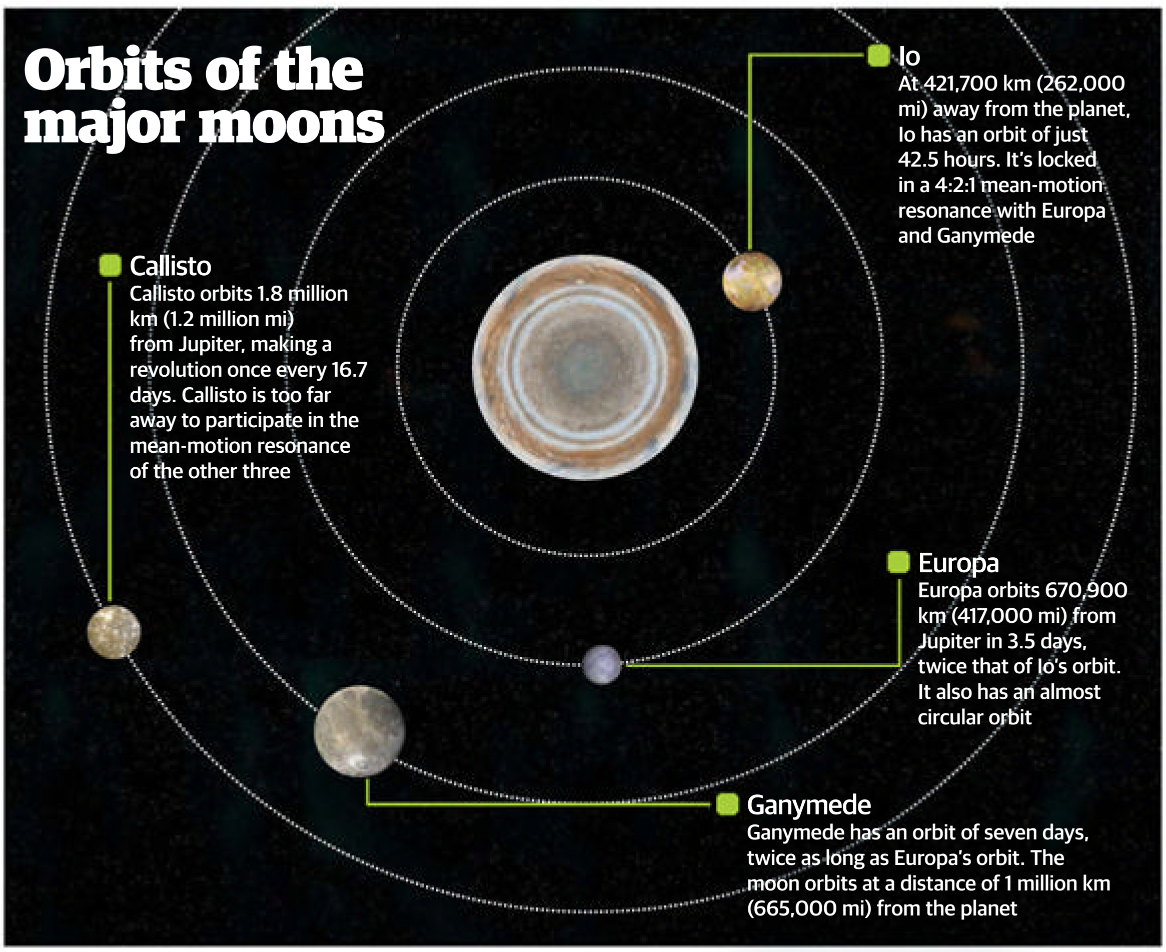
planet, not all of the planet orbits at the same speed. It basically has three different systems - the atmosphere at the poles rotates about five minutes faster than the equatorial atmosphere, which is a little bit slower than the rotation of the magnetosphere (it clocks in at just under ten hours, the official rotation period).

Jupiter is about more than just its size, of course. It has a very striking and unusual appearance, with moving bands of red, orange, white and brown. The planet is the fourth-brightest object in our night sky. If you do some long-term observation of Jupiter, you might notice that at some point it appears to move backwards, or in retrograde, with respect to the stars. That's because the Earth overtakes Jupiter during its orbit once every 398.9 days. You'll also see that Jupiter never appears completely illuminated – its phase angle, the angle of the light reflected from the Sun, is never greater than 11.5 degrees. To see the entire planet, we had to visit it. ●


Jupiter's surface area is over 120 times greater than Earth's


The impact site of Comet Shoemaker-Levy 9, which collided with Jupiter in 1994


A near-infrared image of Jupiter's volcanic moon Io



The Galilean moons

Io

Io is the innermost of the Galilean moons, and also the fourth-largest moon in the Solar System at 3,642 kilometres (2,200 miles) in diameter. Unlike most moons, Io is mainly silicate rock and has a molten core. That's probably why it has more than 400 active volcanoes, making it the most volcanically active body – moon or planet.

Europa

The second-closest Galilean moon to Jupiter, Europa is also the smallest of the four moons. It's slightly smaller than our own Moon with a diameter of around 3,100 kilometres (1,940 miles). It has a smooth surface of ice and probably has a layer of liquid water underneath, leading to theories that life may be able to exist on this moon.

Ganymede

Ganymede is the largest moon in the Solar System – at 5,268 kilometres (3,300 miles), it's actually larger than the planet Mercury, although it has half the mass. This moon is also the only known moon with a magnetosphere, probably due to a liquid iron core. This moon also comprises both ice and silicate rock, and it's believed that there may be a saltwater ocean below the surface.

Callisto

Being the outermost Galilean moon, Callisto is furthest from Jupiter and its strong radiation and therefore might be a good base for exploring the planet. The moon is composed equally of water-ice and rock, and there's also the possibility that it may be able to support life. It has a heavily cratered surface as well as a thin atmosphere, which is most likely composed of oxygen and carbon dioxide.

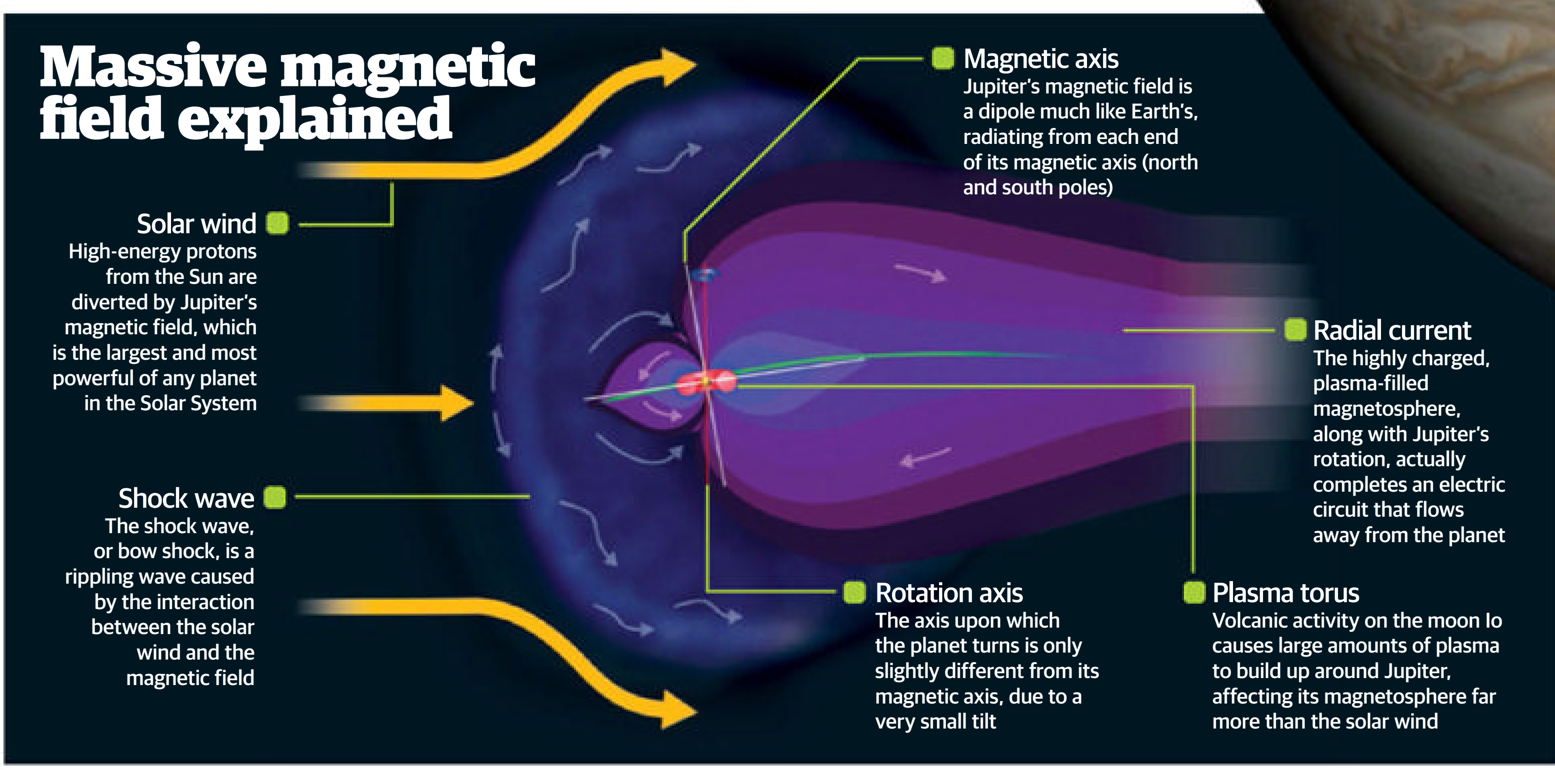
Jupiter inside and out

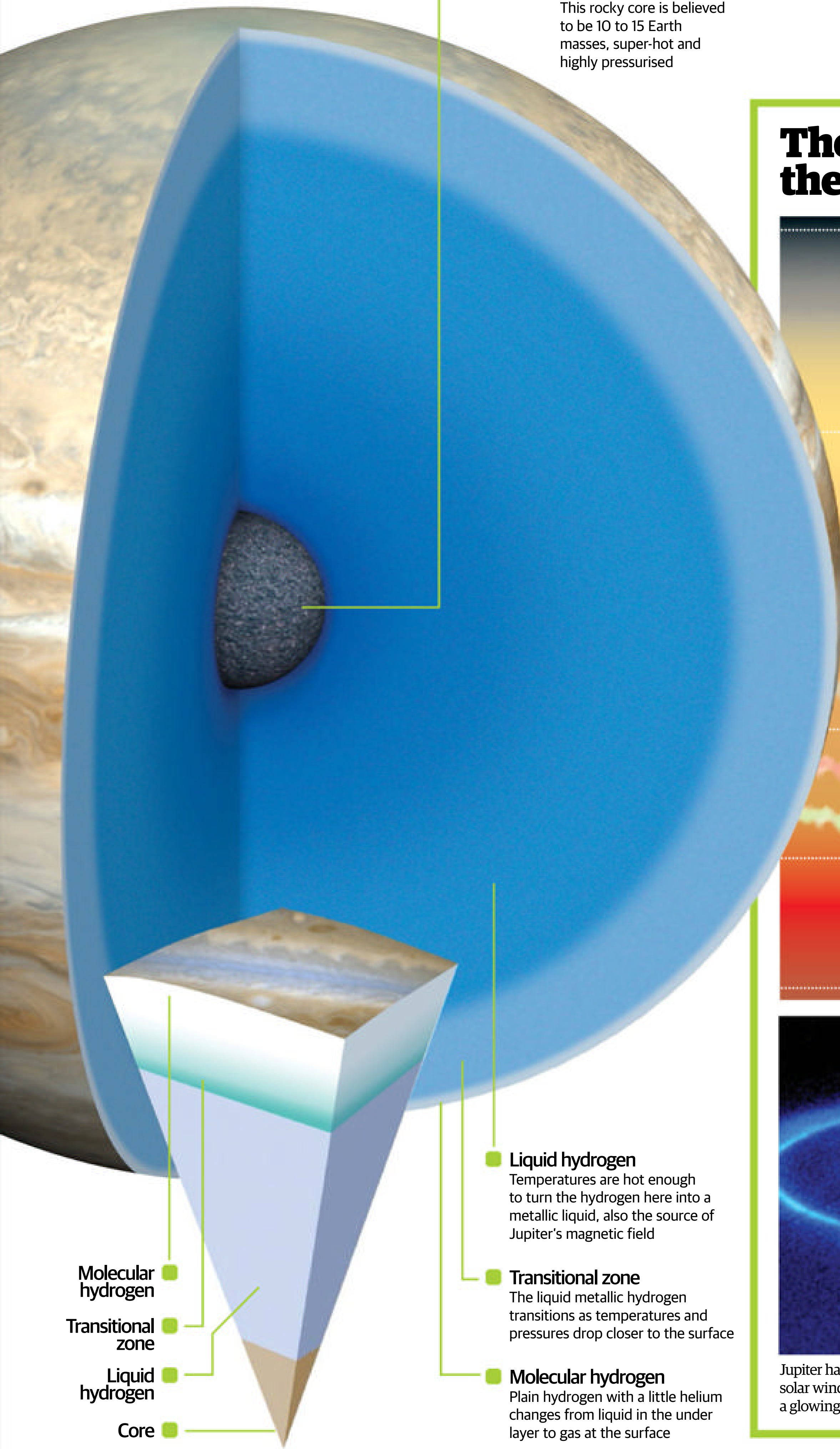
A rocky core surrounded by liquid metallic hydrogen, Jupiter gets more interesting the closer you get to its centre

Since Jupiter is a gaseous planet, it's mostly about atmosphere. The gases just get denser, hotter and under greater pressures as you go further towards the centre. Jupiter is about 90 per cent hydrogen and ten per cent helium – volume-wise. But if you measure the composition of the planet by mass, there's 75 per cent hydrogen and 24 per cent helium. There are also traces of ammonia, methane, carbon, hydrogen sulphide and other elements and compounds. We don't know that much about the interior because no probe has penetrated the cloud cover below 150 kilometres (93 miles). But we do think that Jupiter isn't entirely gaseous; we believe it has a rocky core containing silicates and other elements, with a mass that is 10 to 15 times that of Earth's mass. The concept of a rocky core is based on gravitational measurements taken by probes, but this model is very uncertain until we get more data from NASA's Juno mission (set to enter Jupiter's orbit in 2016). Current projections for the interior show a layer of liquid metallic hydrogen along with helium surrounding the core, with a layer of molecular hydrogen outside. There is no actual boundary between the liquid and gaseous layers, however.

Temperatures on Jupiter vary widely. In the cloud layer, they are very cold at -145 degrees Celsius (-234 degrees Fahrenheit). As you move further towards the core, as the hydrogen becomes liquid, the temperature reaches 9,700 degrees Celsius (17,500 degrees Fahrenheit), and the core may be as hot as 30,000 degrees Celsius (54,000 degrees Fahrenheit). The planet is thought to have been much hotter and also much bigger – as much as twice its current diameter – when it first formed. Jupiter generates almost as much heat on its own as it receives from the Sun, via a process called the Kelvin-Helmholtz mechanism. The surface cools, which also results in a loss of pressure. The whole planet shrinks, which compresses the core and causes it to heat up. The pressure at the core may be up to 4,000 GPa (gigapascals). By comparison the Earth's core is at a pressure of 360 GPa. The pressure inside Jupiter is so intense that some scientists believe that the core may actually be gradually liquefying.

Massive magnetic field explained





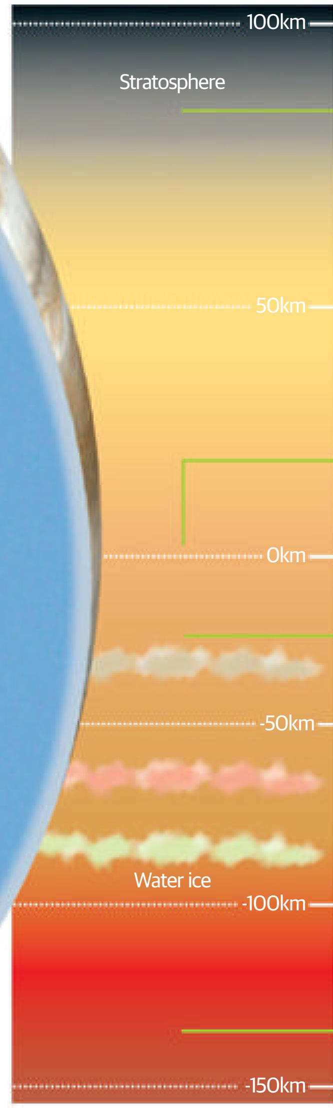
Core
This rocky core is believed to be 10 to 15 Earth masses, super-hot and highly pressurised

Liquid hydrogen
Temperatures are hot enough to turn the hydrogen here into a metallic liquid, also the source of Jupiter's magnetic field

Transitional zone
The liquid metallic hydrogen transitions as temperatures and pressures drop closer to the surface

Molecular hydrogen
Plain hydrogen with a little helium changes from liquid in the under layer to gas at the surface

The structure of the atmosphere

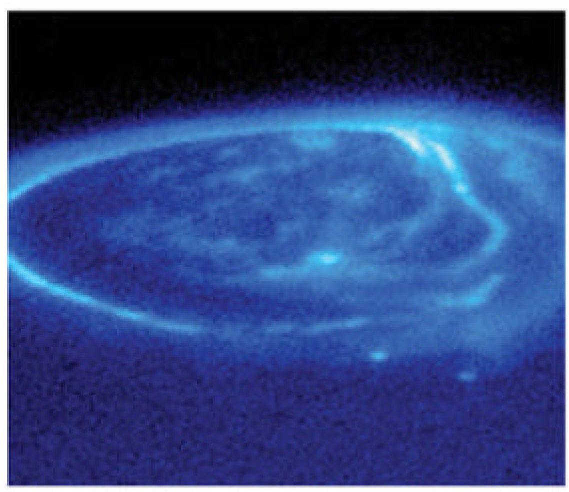


Stratosphere
The stratosphere is still mostly hydrogen, with methane, ethane, acetylene and other light hydrocarbons

Haze layer
Above the cloud layer there's a layer of hydrazine haze, made by interactions between ultraviolet radiation from the Sun and methane in the stratosphere

Troposphere
The upper clouds are the lightest, of ammonia, and get denser as they change to ammonium hydrosulphide, then to water

Gas layer
The 'surface' of the planet is defined by pressure and temperature – both begin to drop as the gases dissipate



Jupiter has auroras just like Earth – charged particles from the solar wind interact with the planet's magnetic field, resulting in a glowing display

In the clouds

It might not have a surface, but the clouds of Jupiter are a fascinating phenomena

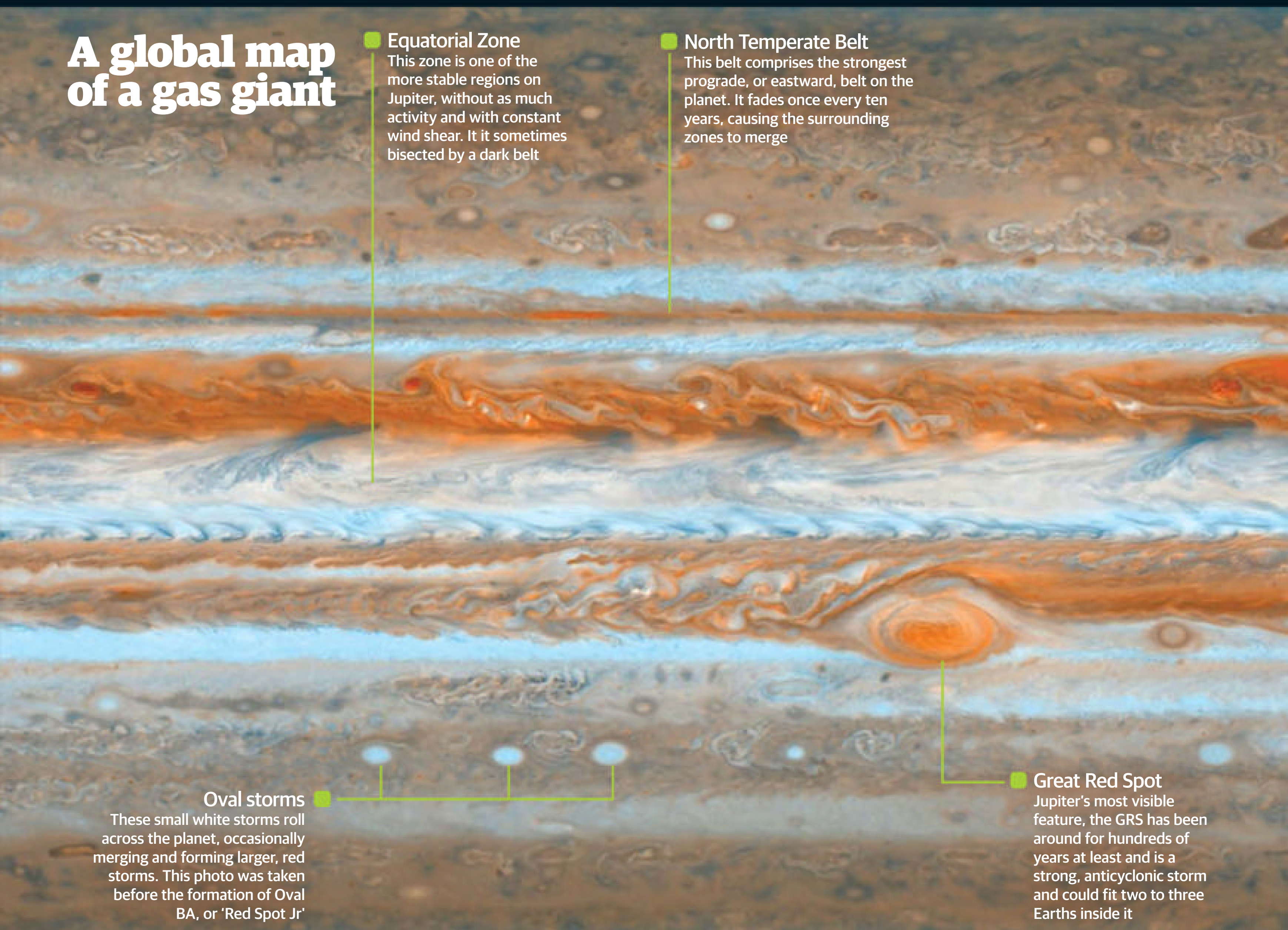
The colours visible in photos of Jupiter are a result of the different layers of clouds in the planet's atmosphere. The cloud layers aren't static, either – they move and flow in complex patterns. The approximately dozen lines are called bands, and there are two different kinds: the lighter-coloured areas are known as zones, while the dark-coloured ones are called belts.

Zones comprise dense, ammonia ice clouds in higher areas and are colder, while the dark belts contain thinner, lower, warmer clouds. Their red and orange colours come from sulphur and phosphorous, while carbon may create some of the lighter grey colours.

The equator is circled by a zone, known as the Equatorial Zone (EZ), that stretches from seven degrees north and seven degrees south of the equatorial line. There are dark Equatorial Belts (EB) extending from the EZ at 18 degrees north and south on either side. Tropical zones are on either side of each EB. The zones and belts then alternate until reaching each of the poles, where they become more difficult to distinguish. None of them have perfect boundaries. Many of the belts and zones have names, each with distinctive features and movements. While most have remained fairly constant for as long as we've been observing and recording them, there are both temporary and permanent changes in things like features, appearance and wind speed. Sometimes the Equatorial Zone is bisected by a dark band, and irregular dark areas known as 'hot spots' can come and go.

Each belt is surrounded by wind jets, called zonal atmospheric flows. The transitional areas from the belts to the zones (headed towards the equator) are marked by westward, or retrograde jets. Eastward, or prograde jets, mark the transitions from zones to belts heading away from the equator. These are more powerful than the retrograde jets, and can reach speeds of up to 100 metres per second or 328 feet per second (360

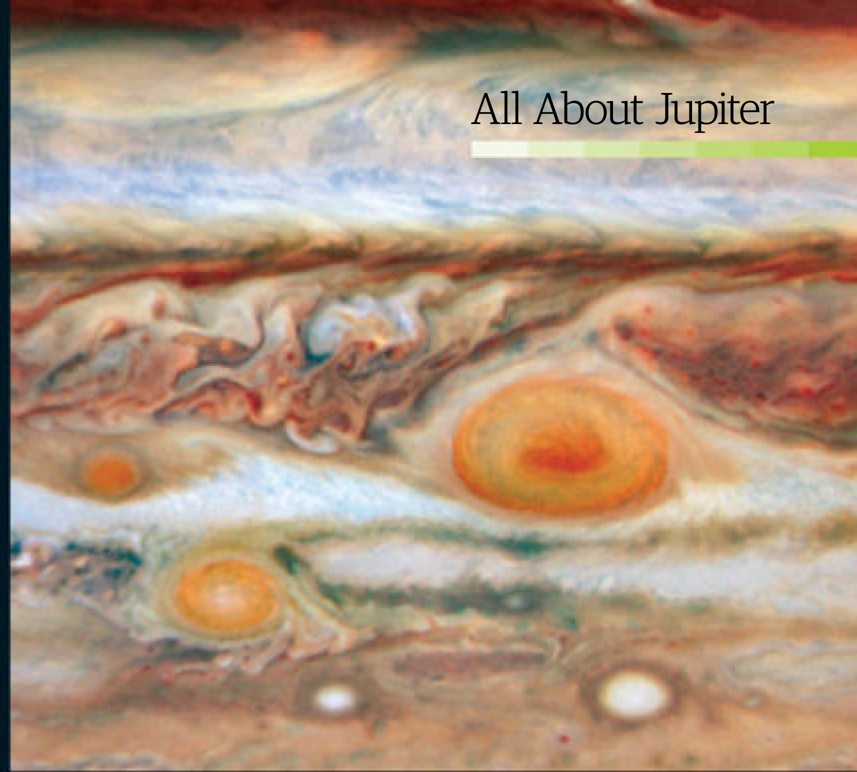
A global map of a gas giant



kilometres per hour or 224 miles per hour). In the belts, the wind shear is cyclonic - the air flows in the same direction as Jupiter's rotation. Zone wind shear, however, is anticyclonic. The exception to these rules is the Equatorial Zone - it has a prograde jet with very little movement right along the equator.

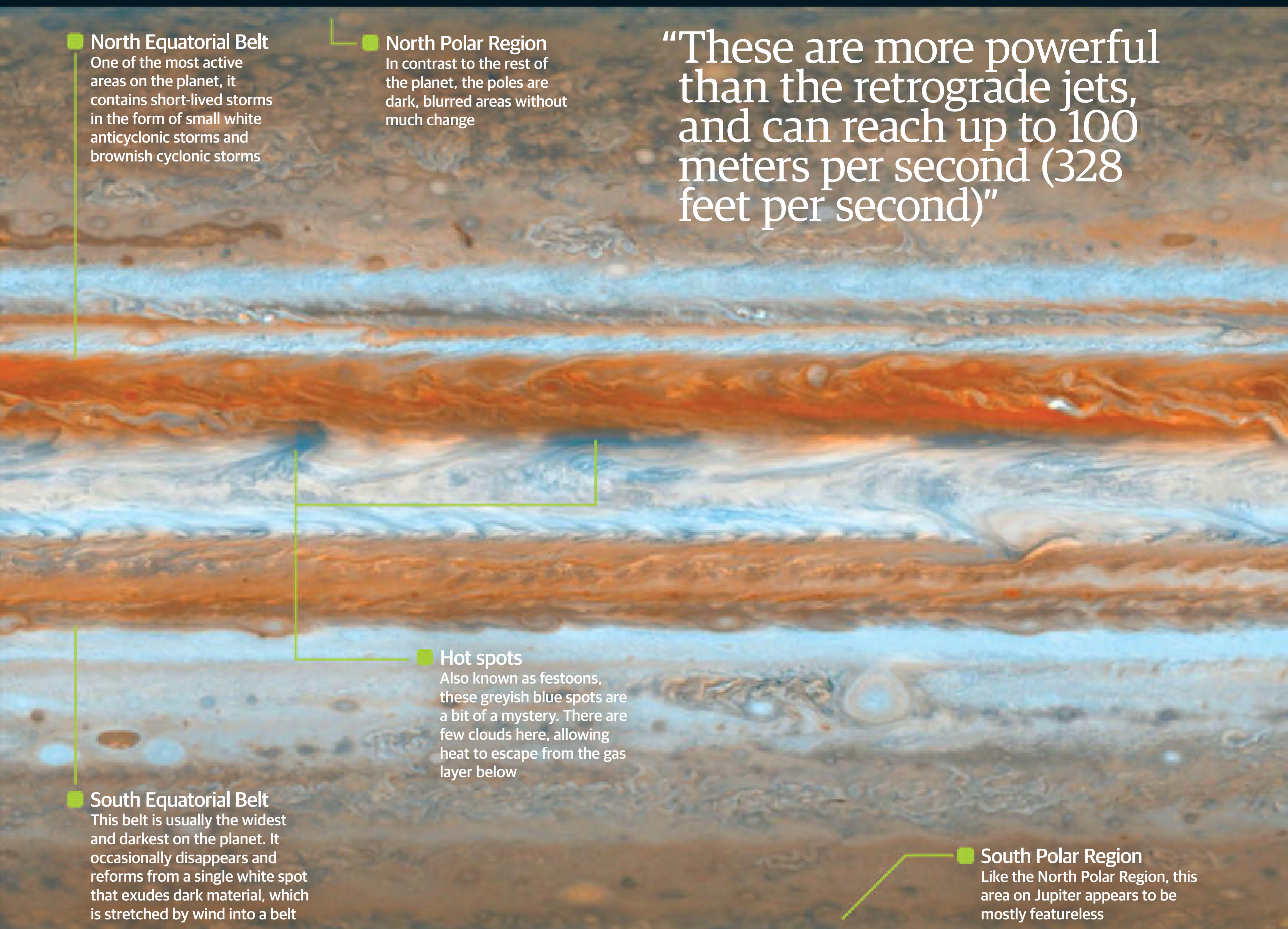
We do not yet know exactly how deep the jets go, but we do know that they exist as far down as the Galileo probe was able to measure, about 150 kilometres (93 miles) below the top of the clouds. We're also not sure what causes this band structure on Jupiter, but one theory is that the belts are areas of downwelling (higher density material sinking beneath lower density material), while the zones are areas of upwelling. The ice clouds rich in ammonia cool and expand, causing the dense light-coloured clouds in the zones. In the belts, the same clouds warm and eventually evaporate. This allows the darker, mineral-laden clouds below to show through.

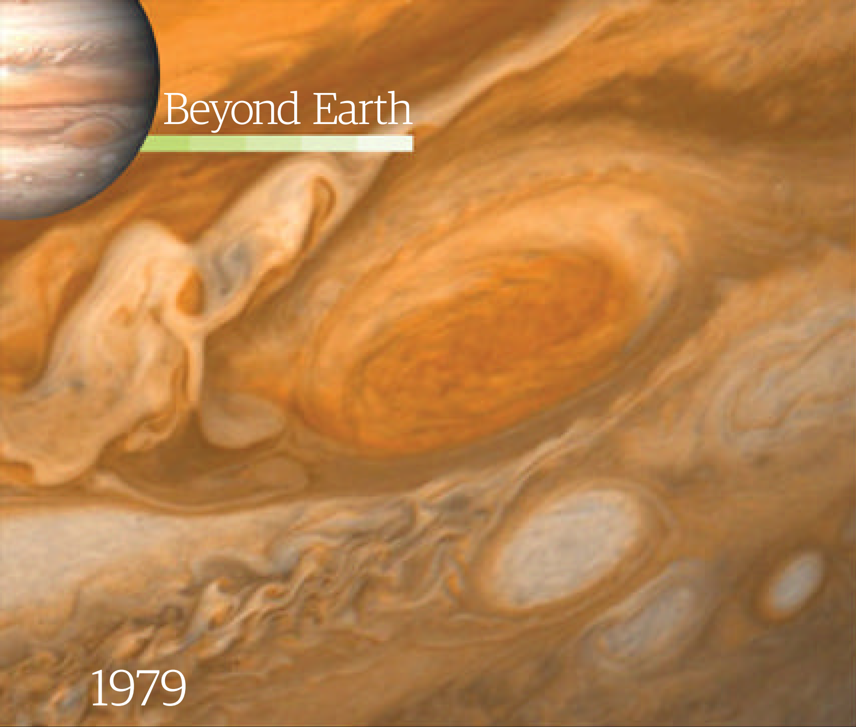
While Jupiter doesn't have seasons because of its small axial tilt, it does have weather patterns. The evaporation and condensation process of water creates dense clouds. These are strong storms, including powerful lightning strikes, mainly in the belts. Most storms on Jupiter tend to be very short, but there are a few major storms that have been raging for a long time. The biggest and most well-known of these is the Great Red Spot, which has been around for a minimum of between 180 and 300 years, and there's also the Oval BA storm (which is sometimes referred to as 'Red Spot Jr').



The Great Red Spot and Oval BA got some company in 2008 when small white oval storms merged and formed a new red spot (on the far left). Its appearance may mean that Jupiter is undergoing climate change and warming near its equator

"These are more powerful than the retrograde jets, and can reach up to 100 meters per second (328 feet per second)"





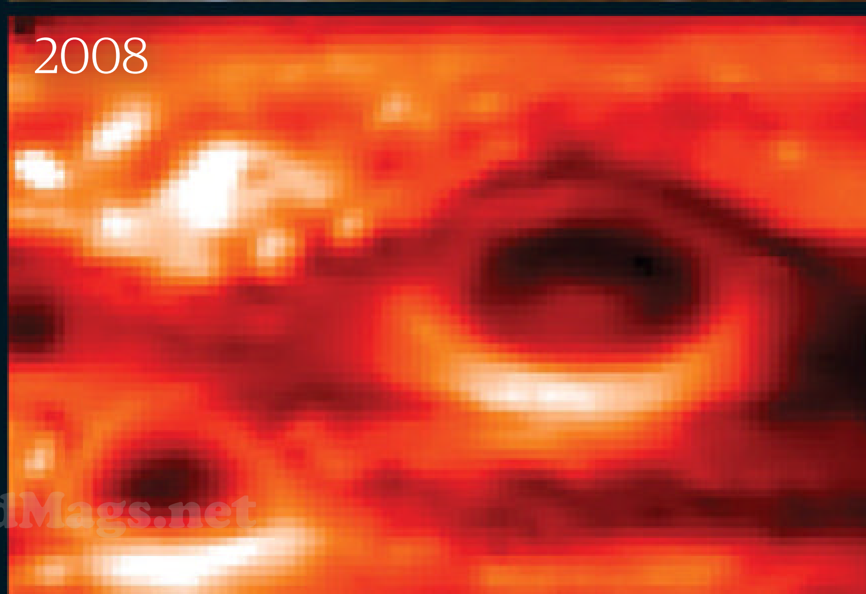
1979

1996

1999

2000

2006



2008

The changing Great Red Spot

A storm with the circumference of Earth that's raged for centuries

Sometimes our storms seem like they're never going to end, but imagine a storm that's been going for hundreds of years. The Great Red Spot is a dark red, anticyclonic storm with high pressure.

It is currently between 12,000 and 14,000 kilometres (7,500 to 8,700 miles) wide north to south and 24,000 to 40,000 kilometres (15,000 to 25,000 miles) east to west. Some data suggests that it was originally much bigger, but its shrinkage doesn't mean that it's disappearing.

The clouds that make up the GRS are higher - at least eight kilometres (five miles) - and therefore colder than the surrounding clouds. Its darkest, reddest area in the centre is significantly warmer than the rest, and actually has a mild clockwise rotation. The colours of the GRS vary wildly - sometimes they're strong, dark reds and oranges, other times, it gets so pale that it disappears, leaving a sort of niche behind in the South Equatorial Belt until it reappears. The colour is linked to that of the SEB - when the GRS is darker, the SEB tends to be lighter, and vice versa. Why has the Great Red Spot lasted so long? We can't be sure, but one theory is that it's continually powered by the intense heat from the planet, there's no landmasses or other formations to disrupt it. It has also absorbed smaller storms in the past.

1979
Taken by Voyager 1, this image of the GRS shows details of the storm's cloud patterns. The wavy pattern on the left is due to variable wave motion. The white spot visible has a diameter roughly equivalent to Earth's.

1996
Another white storm in this image trails along with the GRS, which is at a more elongated and salmon-coloured stage. Note that the equatorial belt in which it resides is about the same colour.

1999
The storm and its belt are still about the same colour, but the GRS appears to be getting darker and the belt, lighter. This image also shows two of the three white spots that would eventually become the Oval BA.

2000
This Hubble image shows a darker and more compact GRS. It also features the Oval BA, or 'Red Spot Jr.' A similar merger centuries ago may have created the original GRS.

2006
This image taken by Hubble shows a darker and more compact GRS. It also reveals the Oval BA.

2008
Obtained by the VLT, this image was taken in an infrared wavelength which is sensitive to Jupiter's atmospheric temperatures in the 300 to 600 millibar pressure range.

A hidden ring system

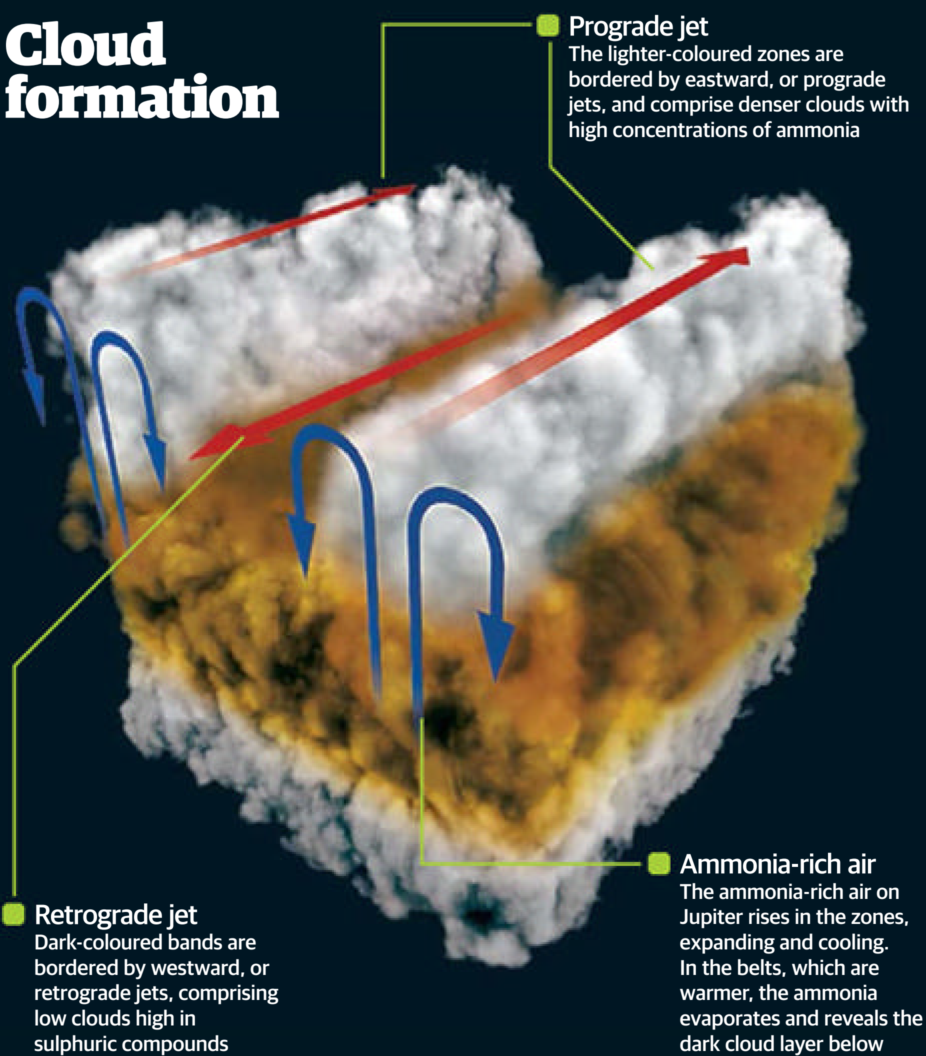
When it comes to rings in our Solar System, Uranus and Saturn get all the attention. But it turns out that Jupiter has a ring system of its own. It was first discovered by the Voyager 1 probe in 1979, while Galileo revealed more about the rings in the Nineties.

The Jovian ring system consists mainly of dust and has four main components. The two outer rings are wide and faint, and they are named after the moons that connect them together. The Thebe gossamer ring is 97,000km (60,300 mi) wide and has a radius of 129,000km (80,200 mi) to 226,000km (140,400 mi), while the next ring is the Amalthea gossamer, with a width of 53,000km (32,900 mi) and a radius of 129,000km (80,200 mi) to 182,000km (113,000 mi).

The main ring is the thinnest, but also the brightest. It has a radius of 122,500km (76,100 mi) to 129,000km (80,200 mi) and is just 6,500km (4,000 mi) wide.

The inner ring is a halo at 30,500km (18,600 mi) wide and with a radius of 92,000km (57,200 mi) to 122,500 km (76,100 mi). While the other rings look reddish, the halo ring appears blue and is the thickest ring. The other rings are made up of particles coming off the tiny moons located within them, while the halo ring is likely formed from particles sucked towards the planet from the main ring.

Cloud formation



Jupiter in numbers

Fantastic figures and surprising statistics about the gas giant

1,321

This is how many Earths could fit inside Jupiter

2.4 times

How much more you would weigh on Jupiter if you could stand on it, due to its stronger gravity

64

Of Jupiter's 64 natural satellites, most of them measure less than five kilometres (3.1 miles)

1st

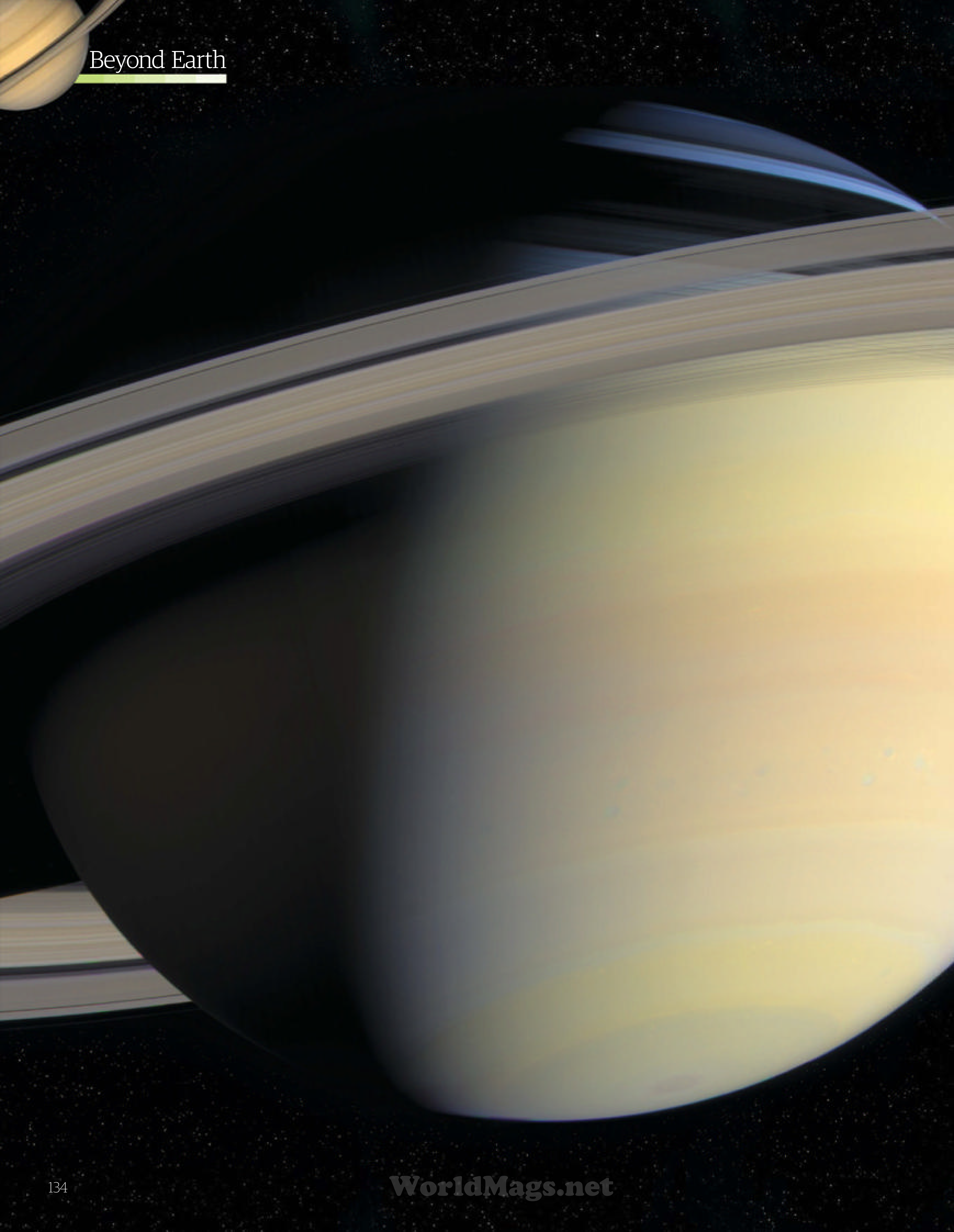
The Galilean moons of Jupiter were the first objects in the Solar System discovered by telescope

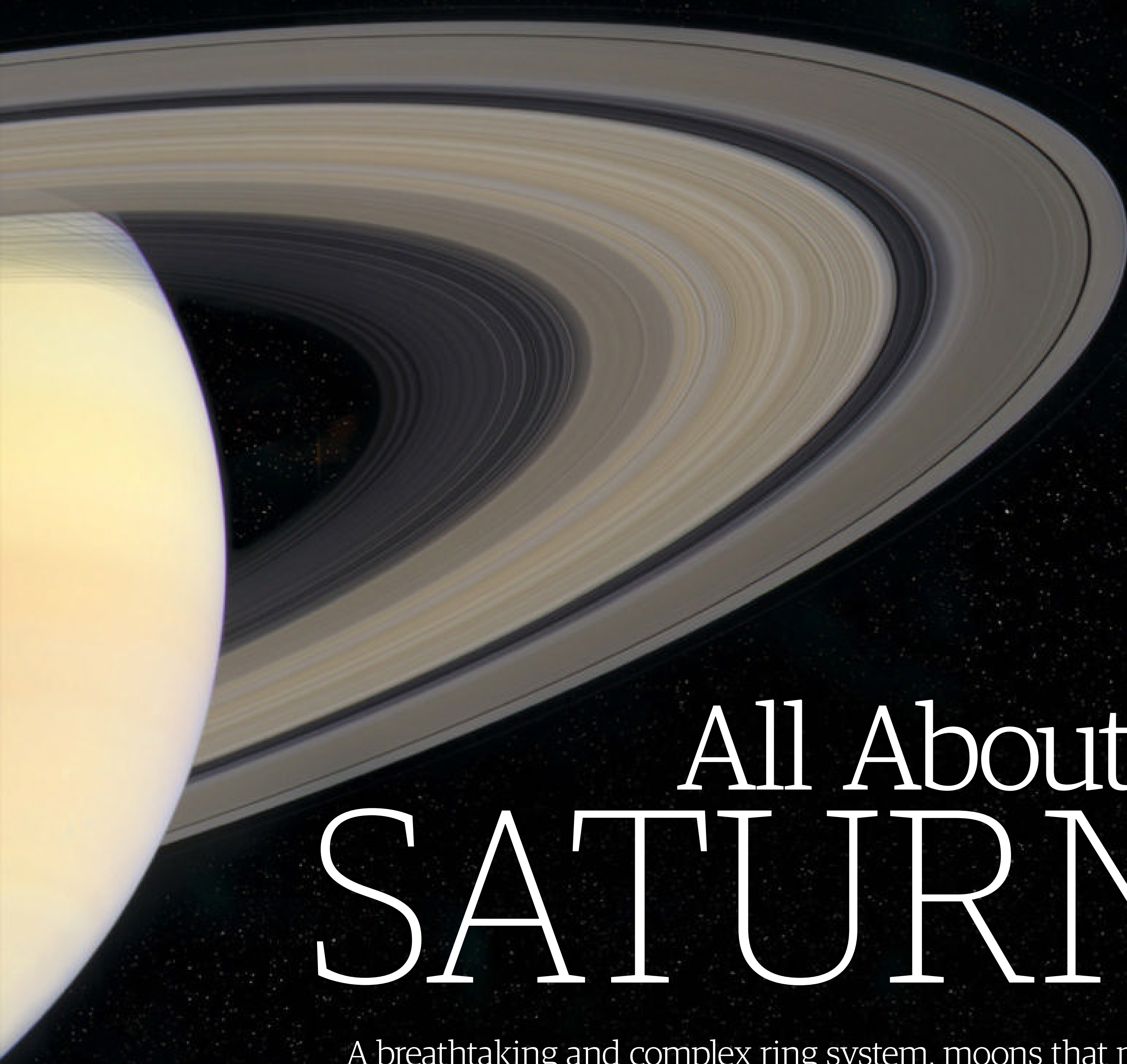
318 times

The mass of Jupiter is 318 times greater than the mass of Earth and 2.5 times that of all the other planets in our Solar System combined

50km

The thickness of the clouds and storms on the planet





All About... SATURN

A breathtaking and complex ring system, moons that might have the capacity to support life and awesome storms that rage at over 1,000mph. There's good reason why this beautiful planet is called the 'jewel' of the Solar System

Gas giant Saturn is the second-largest planet in the Solar System behind Jupiter and the sixth planet from the Sun. As such, it is the most distant planet that is easily visible with the naked eye from Earth. From here, it looks like a bright yellowish point. That doesn't mean that you'll be able to see the rings, though – you will need at least some strong binoculars if you hope to see them.

Saturn is more than 95 times more massive than the Earth, although it has just one-eighth the density. In fact, with a density of just 0.687 grams per cubic centimetre (0.397 ounces per cubic inch), it is less dense than water, meaning that it would float in an ocean if there were one big enough to hold it. Saturn is often compared to Jupiter; the two planets have similar compositions, and both have systems of cloud bands with storms that take place on the surface – although Jupiter's dark areas are much darker and its storms are much more frequent and severe than Saturn's. It's almost like Saturn is a smaller, blander version of Jupiter – but then there are those fascinating rings.

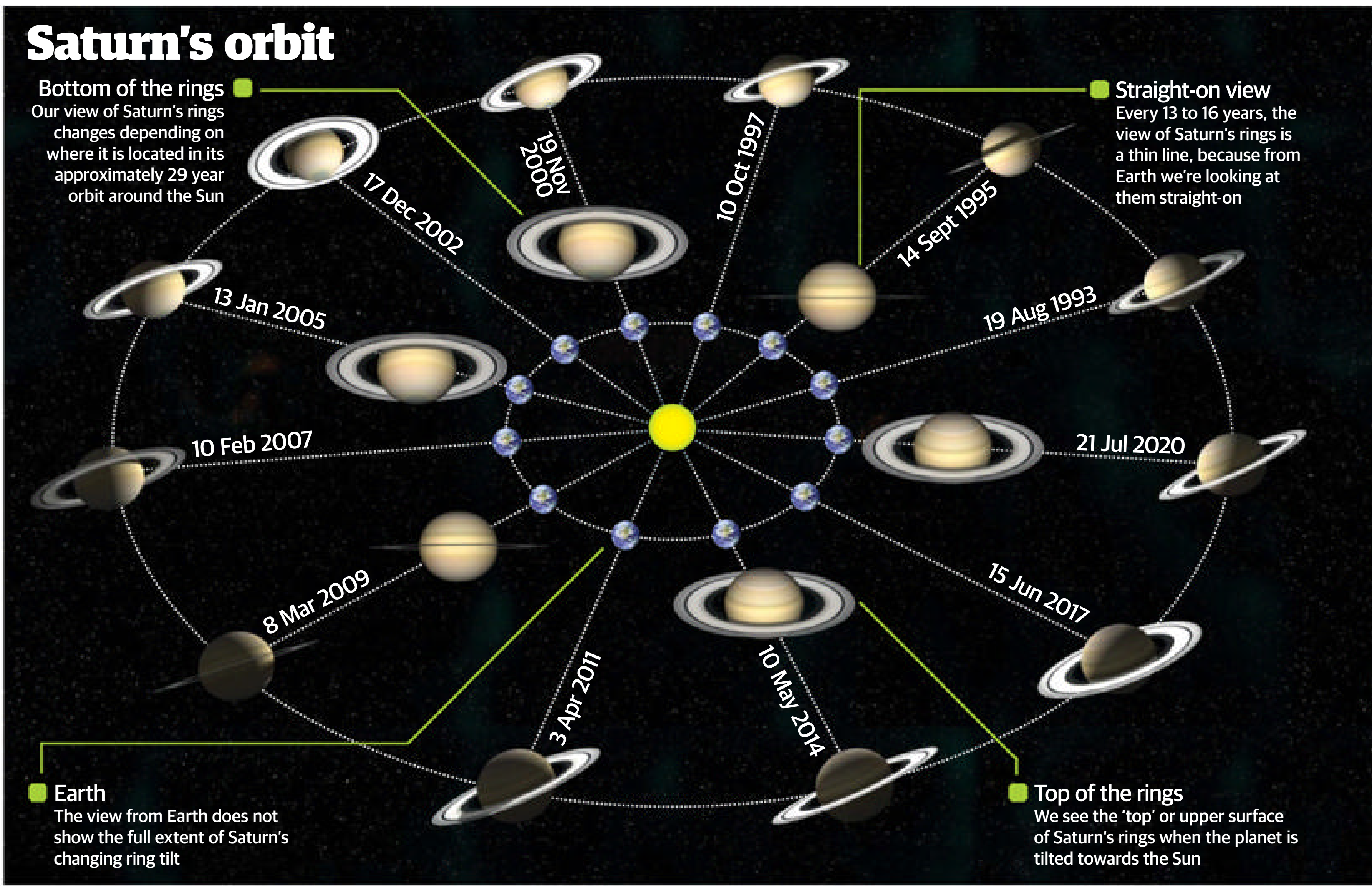
Saturn has become known as the 'jewel' of the Solar System for its appearance. But it didn't gain that moniker until we began to learn about the rings. Italian astronomer Galileo Galilei used a telescope in 1610 and spotted what we now know as Saturn's ring system (although Christian Huygens was the first to identify them as actual rings). The planet has nine rings and three arcs, with two different divisions. They might have originated with some of the nebulous material left over from Saturn's formation, or the rings could have come from a moon that got too close to the planet and disintegrated. Most researchers believe that the rings can't be as old as Saturn itself.

Some of the planet's 62 moons have serious impacts on the rings, either contributing to the matter within them or helping to shape them with their own gravitational pulls. Most of Saturn's moons are so tiny that they're less than ten kilometres (6.2 miles) in diameter, but some of them are unique in the Solar System. Titan, for example, is the biggest, comprising approximately 90 per cent of the mass around the planet and is larger than Mercury. It's also the only known moon to actually sport an atmosphere, while Saturn's moon Rhea might even have rings of its own.

On average, Saturn is 1.4 billion kilometres (890 million miles) away from the Sun. It receives approximately one per cent of the sunlight that we get here on Earth. Saturn has an extremely slow orbit, taking around 29.5 years to complete one. This means that although the planet's tilt gives it seasons during the rotation, each of these seasons are a little more than seven years long. Because of the rings, the seasons give us very different views of the planet from Earth – they might tilt 'up', 'down', or on the same plane as Earth depending on where Saturn is located in its orbit (which means that they can seem to disappear unless you're using a very powerful telescope).

But how long is a day on Saturn? We aren't entirely sure. The haze and clouds keep us from being able to directly view the surface of the planet using telescopes or probes, and we know that the clouds generally orbit at a constant speed so we can't use variations to make that determination. In 1980, the Voyager 1 space probe took readings of radio emissions from the planet to measure the rotation of the planet's magnetic field, and gave

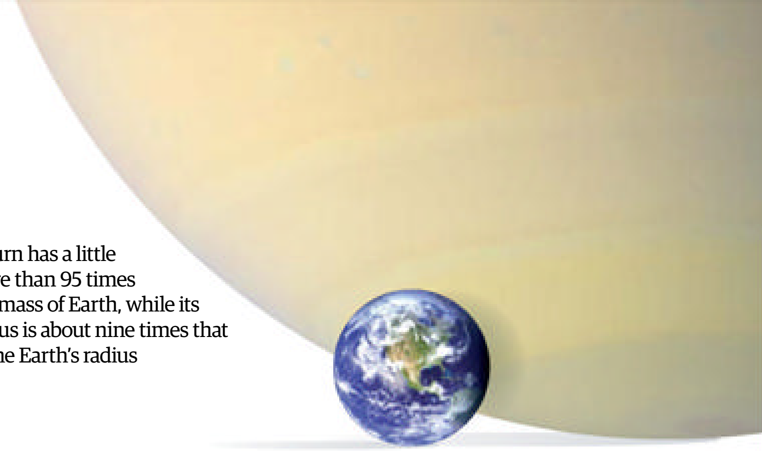
"Saturn is more than 95 times more massive than the Earth, although it has just one-eighth the density"



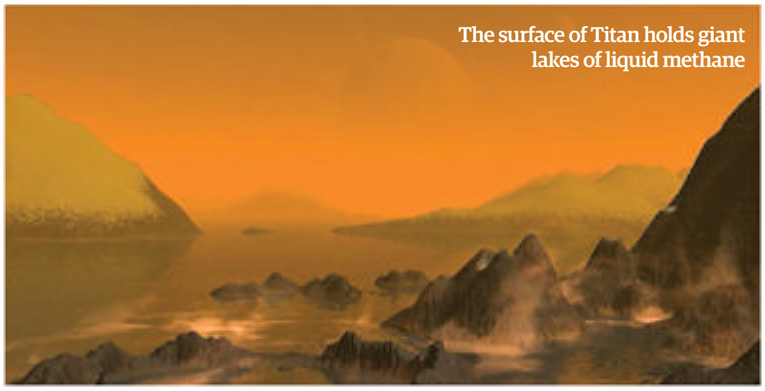
an estimate of ten hours, 39 minutes, and 22 seconds. Then, in 2004, the Cassini spacecraft returned an estimate of ten hours, 45 minutes, and 45 seconds.

While six minutes may not sound like a particularly big difference, it has left scientists puzzled as to whether Saturn is slowing down in its orbit, or whether something else, such as solar wind, is interfering with the emissions. It's most likely to be the latter, however, and the current estimate, which is ten hours, 32 minutes and 35 seconds is a composite made up of various readings.

Regardless, it's a speedy rotation - so fast, in fact, that Saturn looks like a squashed ball as it spins on its axis - and the planet is also approximately ten per cent wider along its equator because of this.



Saturn has a little more than 95 times the mass of Earth, while its radius is about nine times that of the Earth's radius



The surface of Titan holds giant lakes of liquid methane

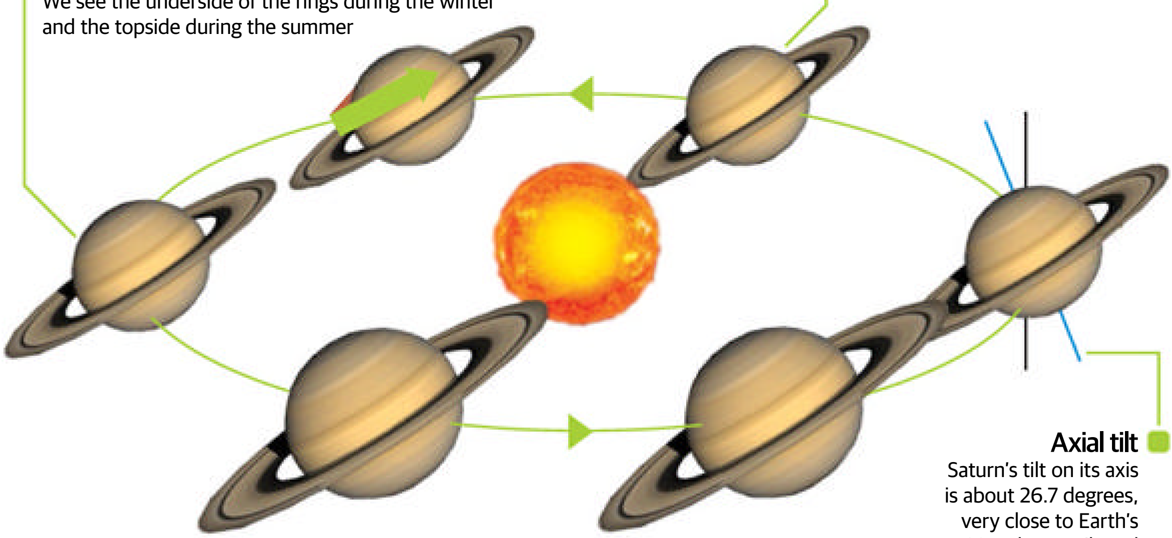
Seasons and tilt

Solstices

Saturn has seasons like Earth, including winter and summer solstices (depending on which hemisphere is facing the Sun). But they last more than seven years. We see the underside of the rings during the winter and the topside during the summer

Equinoxes

Equinoxes signal the beginning of autumn or spring depending on the hemisphere. The seasons and tilt mean that during equinoxes the rings seem to almost disappear from Earth because they're edge-on

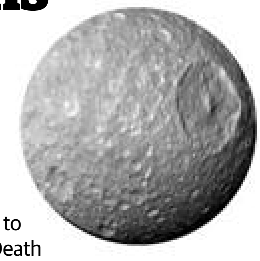


Axial tilt

Saturn's tilt on its axis is about 26.7 degrees, very close to Earth's 23.5-degree tilt and rendered easy to see because of its rings

The major moons

Mimas

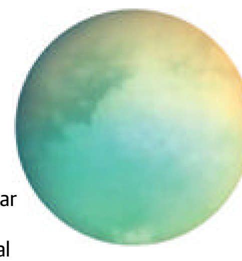


"That's no moon!" But in this case it is. Mimas is known for its appearance, which is similar to the *Star Wars* Death Star because of an extremely large impact crater (140km or 87 miles in diameter) in its northern hemisphere known as Herschel. It is a heavily cratered planet with a surface area that's about the same as Spain's.

Enceladus

Enceladus is the sixth-largest moon of Saturn and is believed to have ice water under its frozen surface. The moon is unique because it's one of just three in the Solar System that has active eruptions – in this case, gigantic ice geysers that shoot out into space. This water ice contributes to the matter in Saturn's rings as well as falling as snow on the moon itself.

Titan



The largest moon of Saturn is particularly interesting as it's the only moon in our Solar System known to have an actual atmosphere around it. While we could obviously never live on Saturn, some think that Titan is a viable option for colonisation in the future or even for extraterrestrial life. The moon also has liquids on its surface, a feature so far found only on Earth.

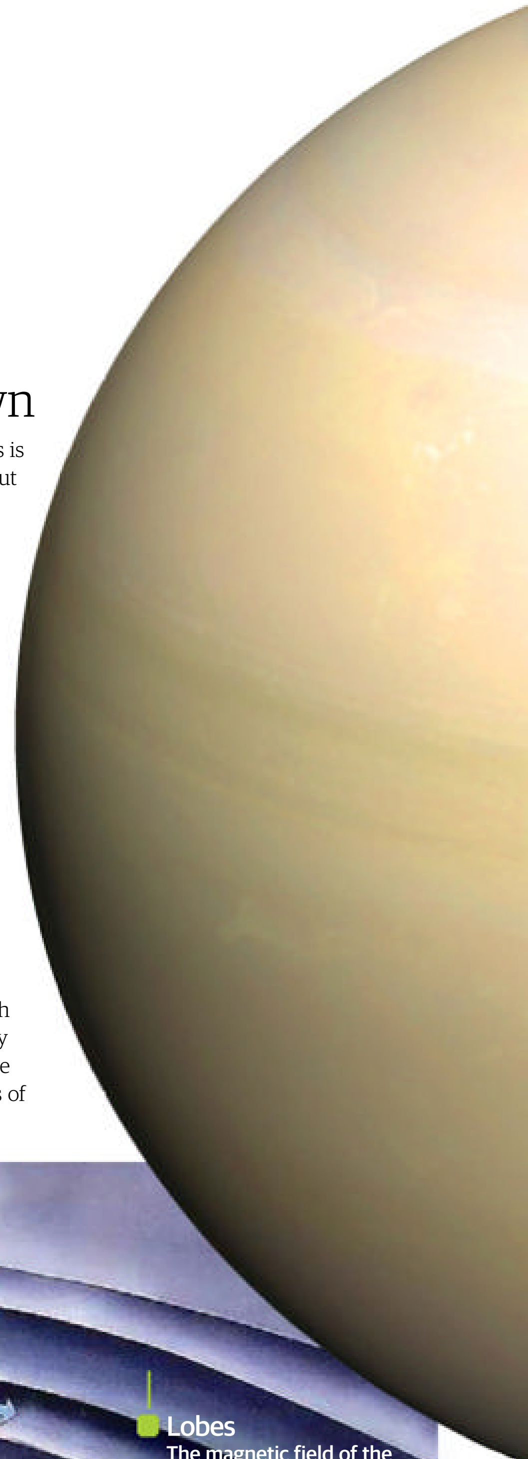
The planets in relation to the Sun

All figures = million miles from Sun

Saturn lies 1.4 billion km (890 million mi) from the Sun on average, and 1.2 billion km (746 million mi) from Earth

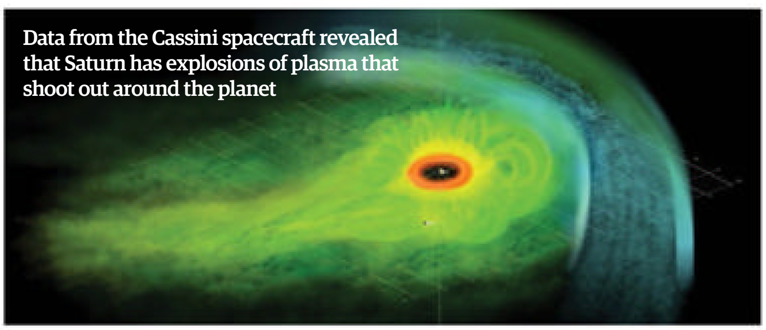
Saturn inside and out

Saturn is often compared with Jupiter, but it can hold its own



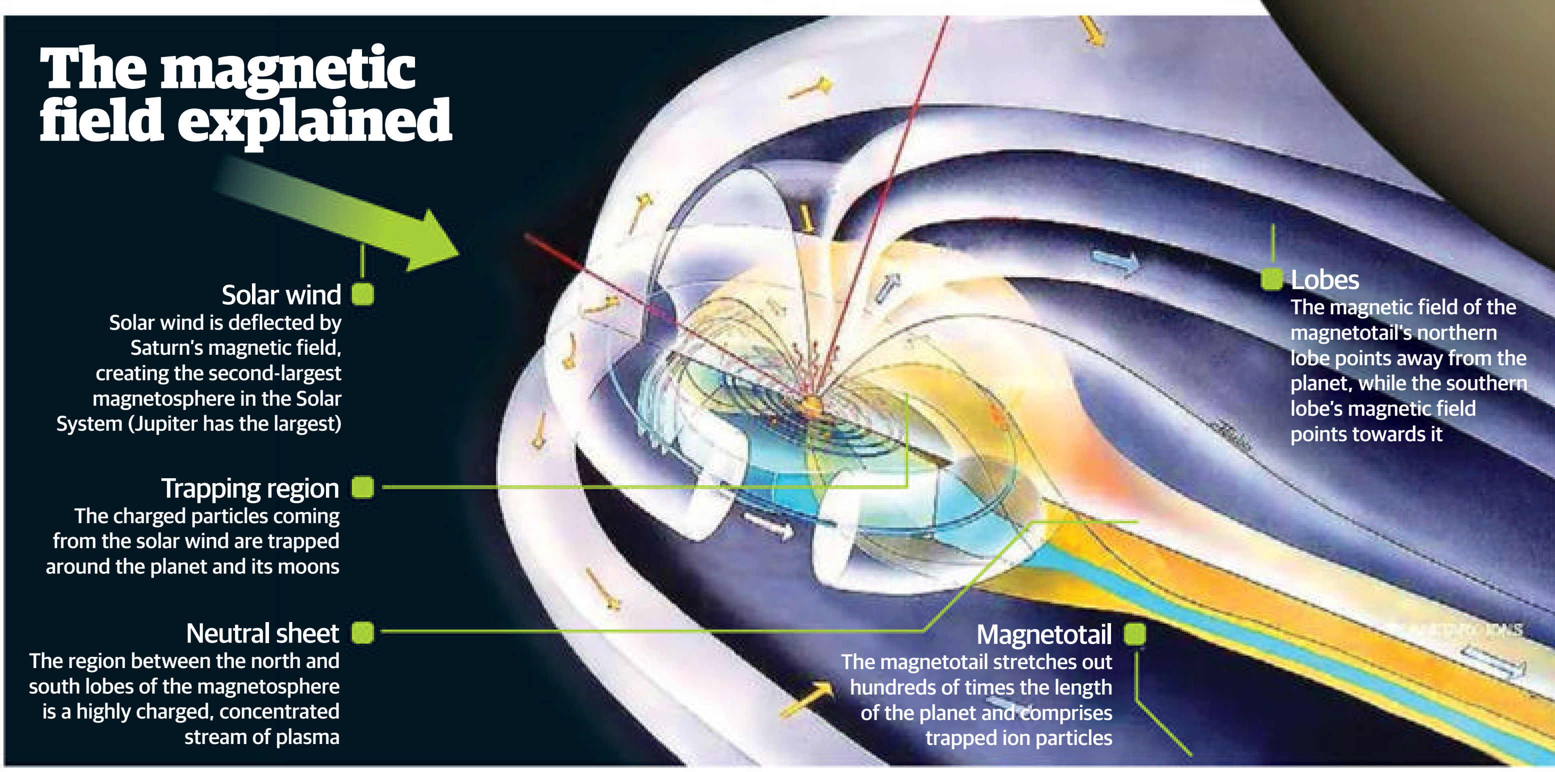
Saturn is one of the gas giants because it has no solid surface and it's mostly composed of gas. But it does have a rocky core, which is similar in composition to the Earth's. Comprising iron, nickel and silicate rock, it is estimated to be somewhere between 10 and 20 times the size of the Earth's core. Surrounding the core, there's a layer of ice made of ammonia and other elements, then a layer of highly pressurised metallic hydrogen, and finally molecular hydrogen that changes from a liquid to a gas. The outer layers of the planet are different types of ice, including ammonia, ammonium hydrosulphide and water. The cloud cover is mostly coloured yellow by ammonia, and there's a mild weather system. Density, pressure and temperature all increase as you pass through the atmosphere and into the core, resulting in a very hot interior at about 11,700 degrees Celsius (21,000 degrees Fahrenheit). Saturn sends out more than twice as much energy as it receives from the Sun. Some of this is due to gravitational compression, but we aren't sure if that can account for such a huge energy output. One possibility is an interaction between helium and hydrogen in the atmosphere, which may put out heat in the form of friction.

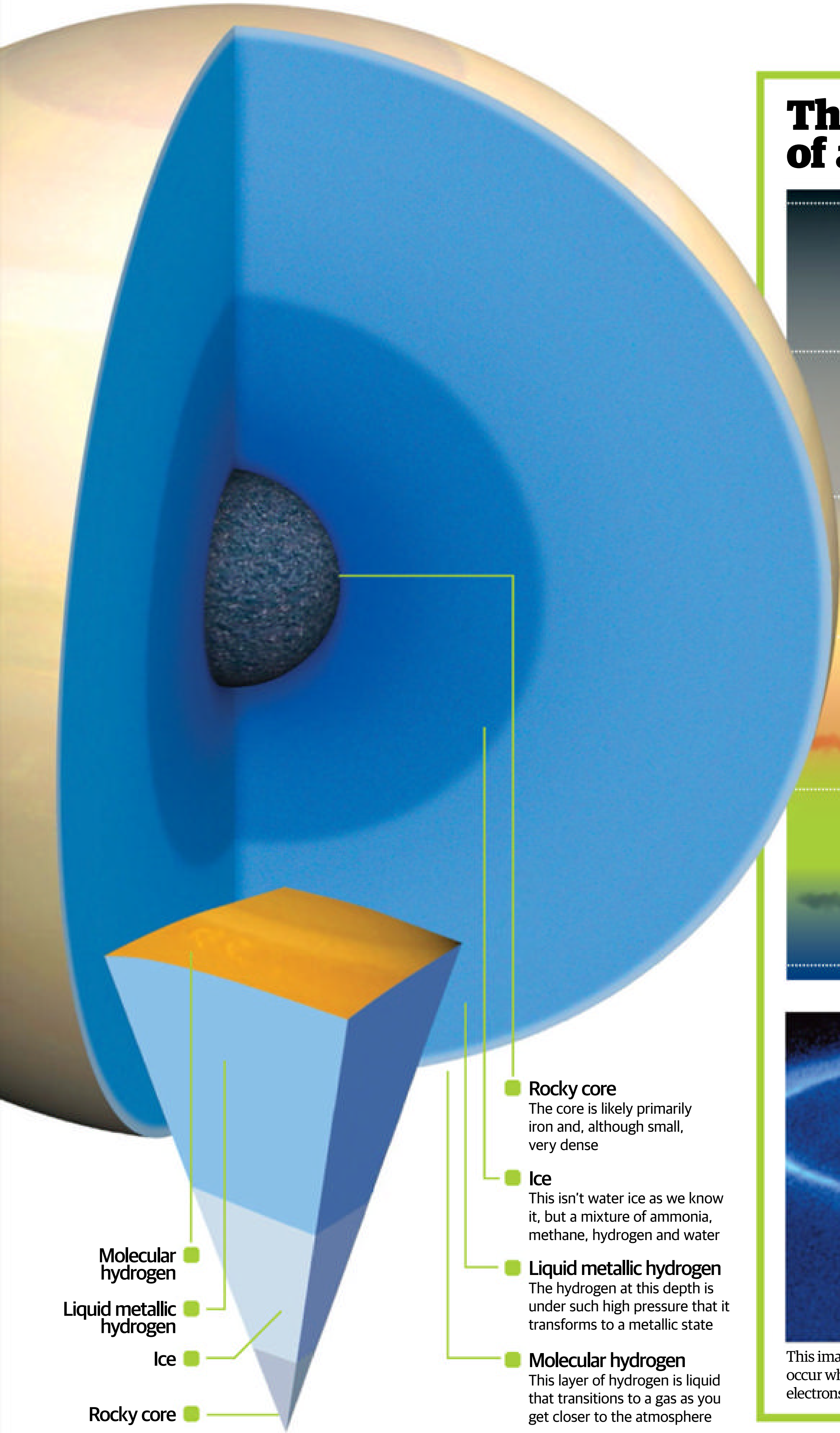
Saturn has a magnetic field 578 times stronger than Earth's. Scientists believe that the metallic hydrogen layer generates an electric current that is responsible for the magnetic field, called a metallic-hydrogen dynamo. The magnetic field is a dipole, with north and south poles. Aside from the rings, one of the most interesting features of Saturn is its auroras. These beautiful light displays have been captured at both the north and south pole regions by the Hubble Space Telescope and the Cassini probe, and appear as circles of light around each pole.



Data from the Cassini spacecraft revealed that Saturn has explosions of plasma that shoot out around the planet

The magnetic field explained





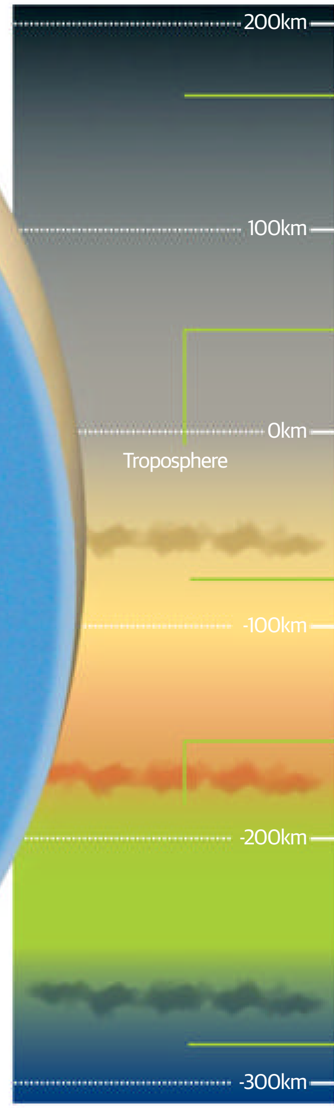
Rocky core
The core is likely primarily iron and, although small, very dense

Ice
This isn't water ice as we know it, but a mixture of ammonia, methane, hydrogen and water

Liquid metallic hydrogen
The hydrogen at this depth is under such high pressure that it transforms to a metallic state

Molecular hydrogen
This layer of hydrogen is liquid that transitions to a gas as you get closer to the atmosphere

The atmosphere of a gas giant



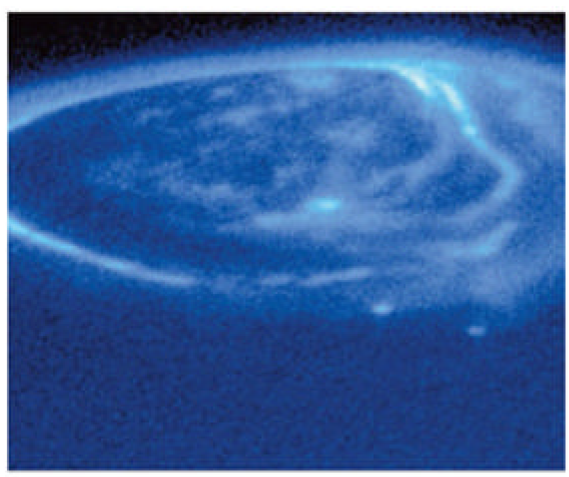
Stratosphere
This upper level is warmed by the Sun. The temperature here varies depending on the weather below

Troposphere
The outer atmosphere comprises about 96.3% hydrogen and 3.25% helium, with traces of other elements

Ammonia ice
Pure ammonia ice clouds sit under the troposphere, which is at 0.5 to 2 bars of pressure and -173°C to -113°C (-280°F to -171°F)

Ammonium hydrosulphide ice
With a pressure of 3 to 6 bars and temperatures of 17°C to -38°C (62°F to -37°F), the ice clouds are ammonium hydrosulphide

Water ice
Temperatures in this level drop to -88°C to -3°C (-124°F to 26°F) and the pressure is greatest at 10 to 20 bars



This image shows one of Saturn's auroras – loops of light that occur when gases in the upper atmosphere are excited by electrons in the planet's magnetic field

In the clouds

Saturn's atmosphere has some similarities to Jupiter's

The composition of Saturn's clouds depends on where you are in the atmosphere. The pressure increases and temperatures drop as you travel further down through the layers and towards the planet's core. At the upper cloud layer, the clouds are made up of ammonia ice, followed by water ice clouds with a layer of ammonium hydrosulphide ice mixed in, and then the bottom layer is ammonia mixed in water droplets.

Much like fellow gas giant Jupiter, Saturn has bands of clouds that are divided into zones and belts. The zones are the lighter-coloured areas and the bands are darker, with the orange and reddish hues coming from sulphuric compounds. The darker clouds tend to be thinner and lower, while the lighter ones are denser and higher. The bands of clouds are named in the same way that Jupiter's are labelled, according to their locations in the northern or southern hemisphere of the planet. However, Saturn's cloud bands are very faint and more difficult to distinguish from each other than Jupiter's. They also widen as they head towards the equator. We weren't able to clearly see the distinctions between some of the fainter bands until the Voyager probes flew by Saturn during the Eighties (although modern telescopes are able to see them).

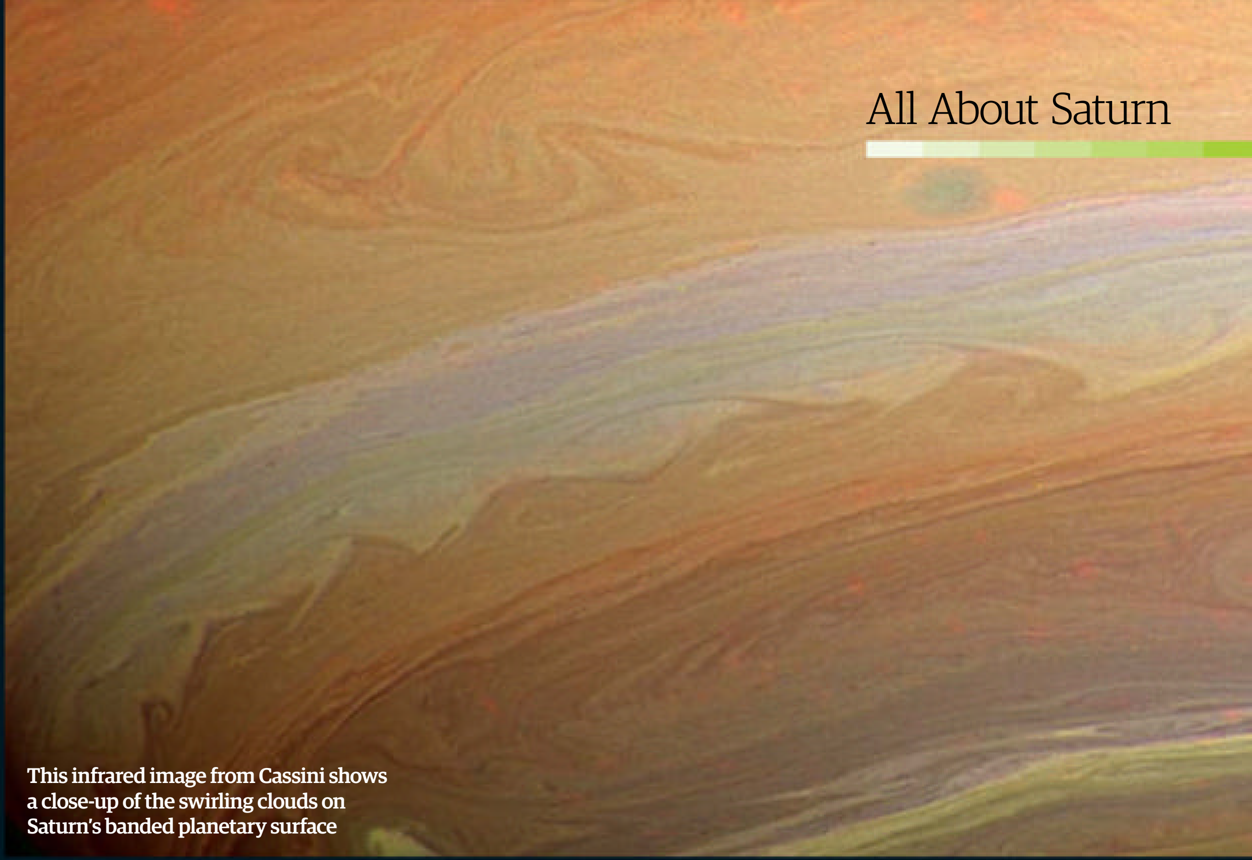
Again, like Jupiter, Saturn has wind jets that alternate westwards and eastwards out from the equator. But Saturnian winds are fast. In fact, reaching maximum speeds of around 1,800 kilometres per hour (1,120 miles per hour), they are the second fastest winds among the Solar System's planets after Neptune's.

Saturn also has some unusual qualities at each of its poles. The north polar vortex has a unique hexagon-shaped cloud pattern, with straight sides estimated to be about 13,800 kilometres (8,600 miles) long, and it appears to rotate at the same speed as the interior of the planet. Scientists are unsure why the clouds have formed this particular pattern. The south pole doesn't have the same

Global picture of a gas giant

kind of cloud patterns, but it is much warmer than the rest of the planet and is believed to be the warmest spot on Saturn.

There isn't a particularly strong weather system on Saturn - it's generally very mild. However, there are the occasional storms that show up as white spots. In 1990, the Hubble Space Telescope managed to capture a massive storm near the planet's equator that was not present during the Voyager encounters. This was an example of what is known as a Great White Spot (named after Jupiter's Great Red Spot). This mass of clouds occurs every 30 years or so, or roughly once every Saturnian year. The Cassini mission also spotted a storm in 2006 near the planet's south pole, which looked a lot like a hurricane on Earth.



This infrared image from Cassini shows a close-up of the swirling clouds on Saturn's banded planetary surface

"The north polar vortex has a unique hexagon-shaped cloud pattern, with straight sides estimated to be about 13,800km long"

The ring system

The feature that makes the jewel of the Solar System shine

Although Saturn isn't the only planet in our Solar System with a system of rings, it's the only one with a system this big. There are billions of tiny particles, mostly ice but with some rocky material, too. Despite the fact that they increase Saturn's brightness, we weren't even aware of its ring system until Galileo observed them via telescope. He was confused a few years later when the rings seemed to disappear, not knowing that they just weren't visible with his telescope when the Earth is on the same plane as Saturn. By the 1800s we knew that the rings were just that - not moons, not a single disc, but many rings comprising tiny particles.

Saturn's ring system is divided into rings, arcs, divisions and gaps. The first seven rings to be discovered were designated with letters of the alphabet A through G, but they were named in order of discovery so from innermost to outermost ring they are D, C, B, A, F, G and E. Three other named rings have been discovered since Ring G, but these are named after the moons that orbit with them: Janus, Epimetheus, Pallene and Phoebe. In addition to the rings, there are two ring arcs, incomplete trails of dust ejected by the moons Methone and Anthe kept in arc formation via resonance with two other gaps. There are also two divisions - the Cassini Division, between Rings A and B, and the Roche Division, a space between Rings A and F. ●

A Ring
This ring is the outermost of Saturn's large, bright rings. It has a width of 14,600km (9,000 mi). There are two gaps within it as well as numerous tiny moonlets.

B Ring
B Ring is the brightest and most massive ring and has a width of 25,500km (15,800 mi). While it doesn't contain any gaps, it does have a wide variety of materials that result in ringlets both bright and dark.

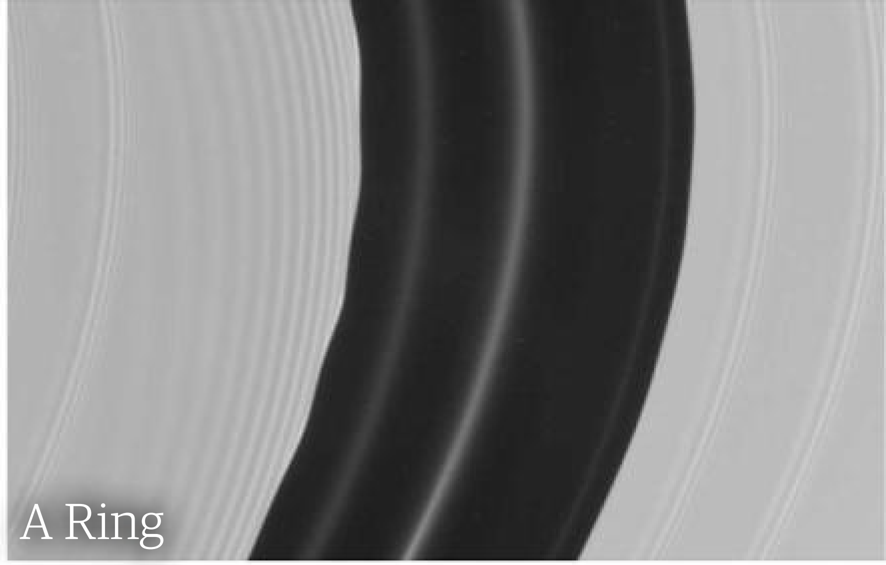
C Ring
This ring is mostly transparent and faint despite its width of 17,500km (10,800 mi). It has two gaps with each containing a ringlet.

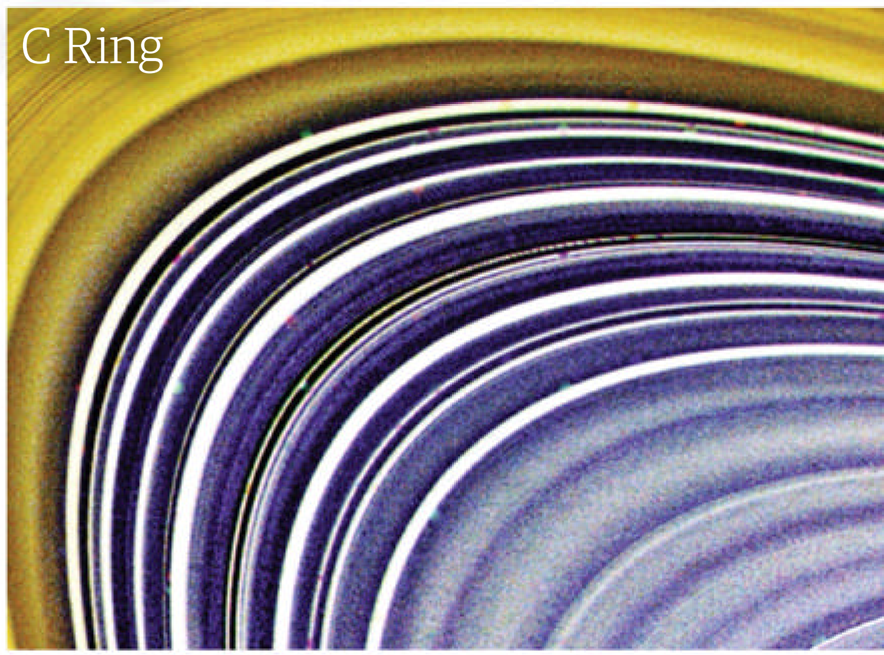
D Ring
The D Ring is the innermost ring and only 7,500km (4,600 mi) wide. It's also very faint and difficult to see.

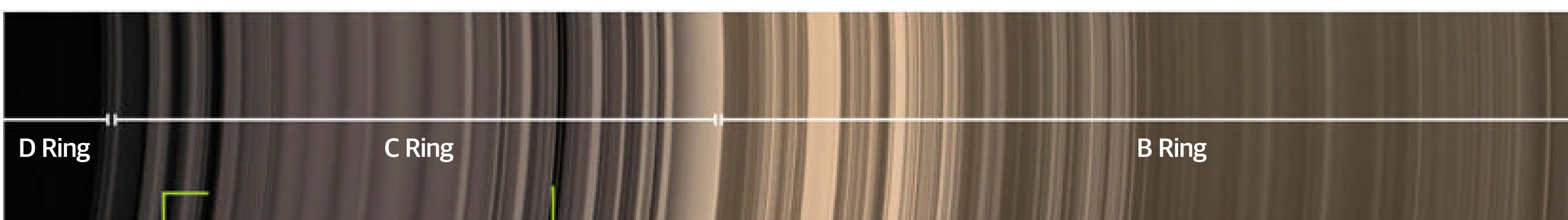
E Ring
Saturn's outermost ring, the E Ring, contains smaller ice particles than all the others. It is 300,000km (186,000 mi) wide.

F Ring
This ring is known as the most active of Saturn's ring system. It has one core ring with a spiral ring coiling around it that is strongly affected by the orbit of the moon Prometheus.

G Ring
The G Ring is halfway between rings F and E, with a very bright inner edge that contains a moonlet called Aegaeon, which is probably the source of the ring's ice particles.



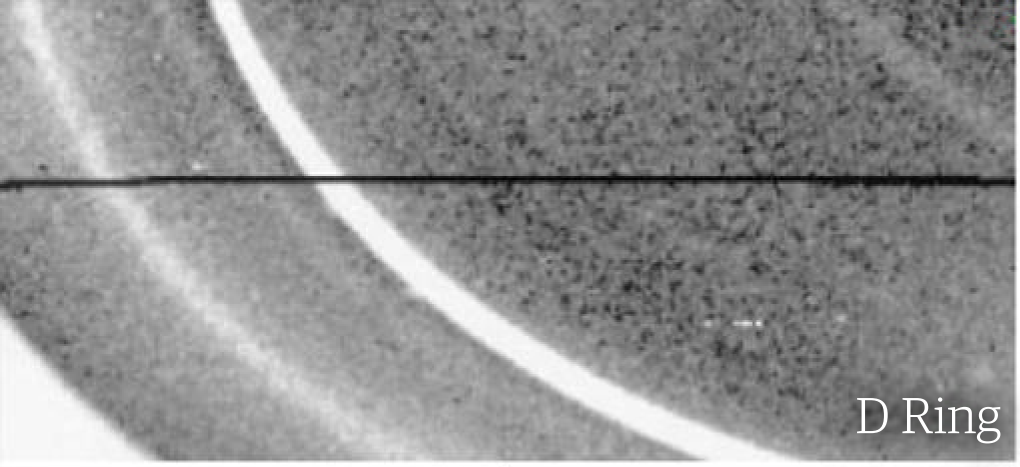


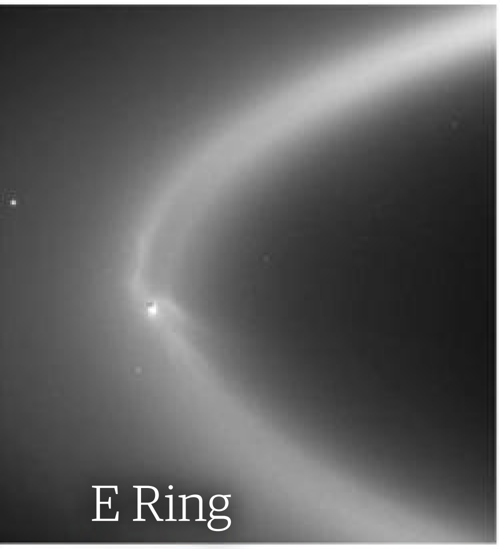


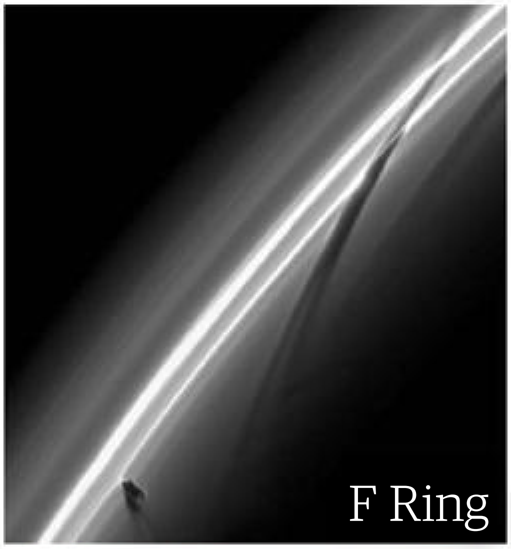
Colombo Gap
This gap, in the inner C Ring, contains a ringlet of its own called the Titan Ringlet (named because it is in orbital resonance with the moon Titan)

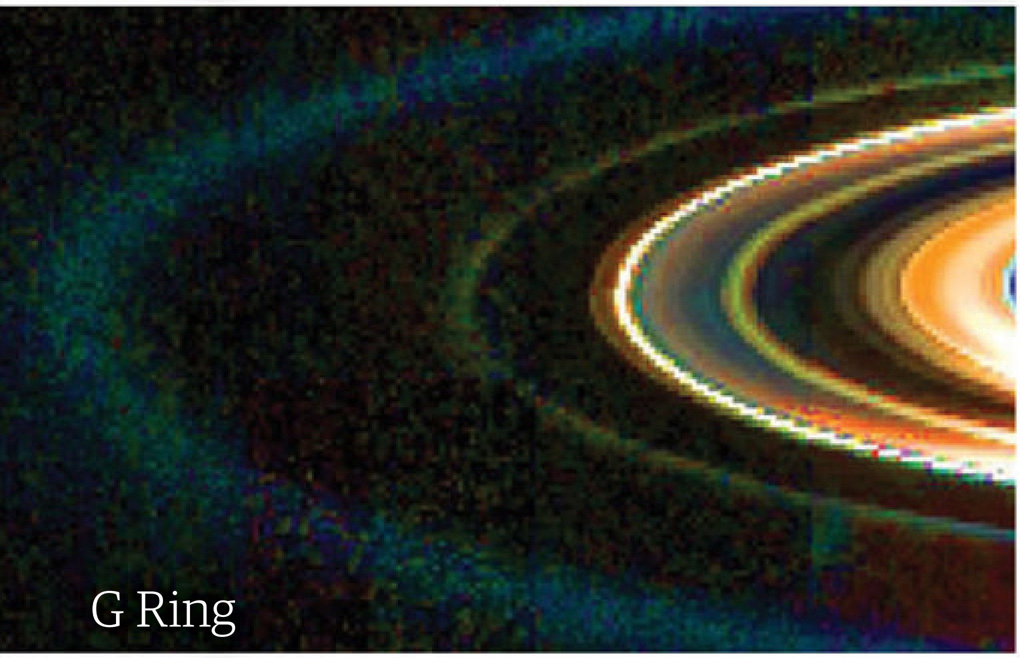
Maxwell Gap
Situated within the outer C Ring, the Maxwell Gap also has a ringlet, but it's not circular and contains wavy structures

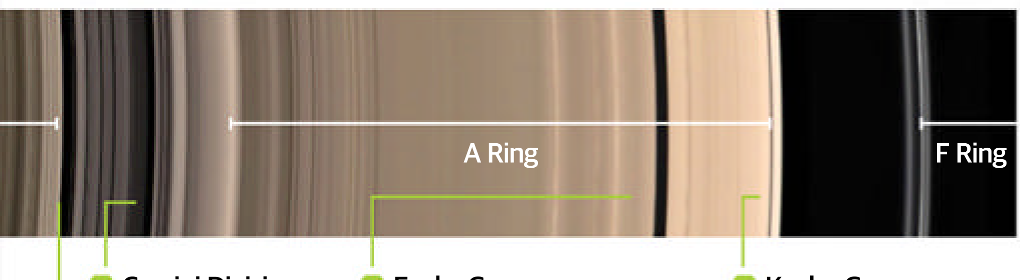
Huygens Gap
Found at the inner edge of the Cassini Division, this gap contains a dense ringlet with an unusual structure caused by resonance with the moon Mimas











Cassini Division
Located between the A and B rings, this apparent gap actually contains darker-coloured ring material

Encke Gap
This gap is located within the A Ring, and its existence is due to the moon Pan orbiting inside. Encke also contains small ringlets and has spiral density waves

Keeler Gap
The moon Daphnis is responsible for this gap located in the A Ring. Daphnis also creates waves around the gap's edges

Saturn in numbers

Fantastic figures and surprising statistics about the ringed planet

578 times

Saturn's magnetic field is 578 times more powerful than Earth's

92%

Saturn and Jupiter together comprise about 92 per cent of the planetary mass of the Solar System

14 years

Saturn's rings seem to disappear about every 14 years or so due to the fact they're so thin and we see them edge-on

80.00kg

A person weighing 80.00kg (176.37lb) on Earth would weigh 85.10kg (187.61lb) on Saturn

75%

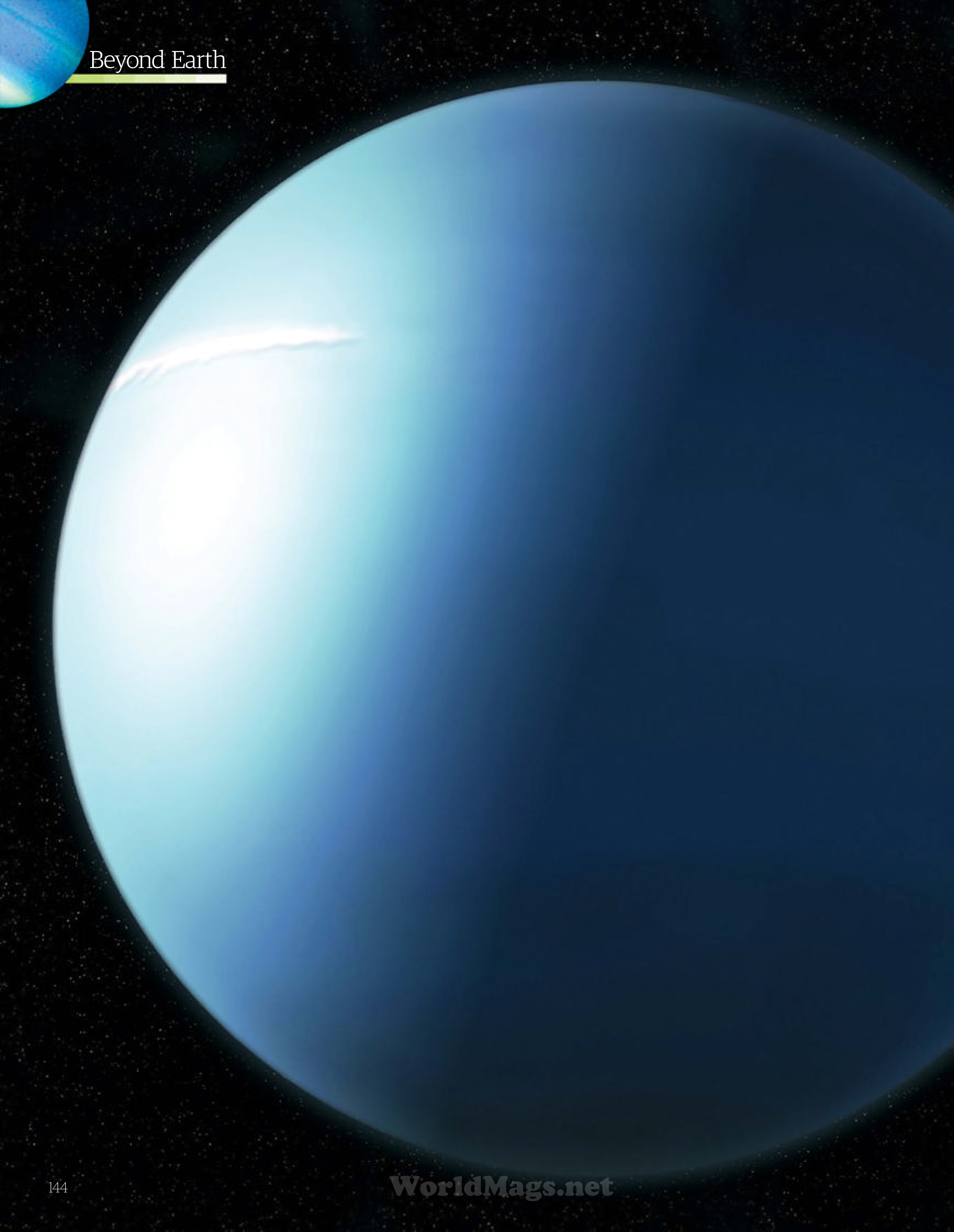
If the Earth had rings that spanned as wide as Saturn's, the rings would be 75 per cent of the way to the Moon

1/8th

Saturn is 1/8th as dense as Earth, so light that if there were an ocean big enough to hold it, it would float

x2

Saturn is twice as far away from the Sun as Jupiter is



All About... URANUS

The Solar System's forgotten planet has long been thought of as a dark, cold, characterless world, but the seventh planet from the Sun has its own unique twist and some fascinating features

While William Herschel officially discovered Uranus in 1781, he wasn't the first to observe it. Others thought it was a star and Herschel himself called it a 'comet' before deciding that it was, in fact, a planet - and the first one discovered by telescope. Although Uranus can be seen from Earth with the naked eye, it's so dim and has such a slow orbit compared to the other known planets that it didn't register as one. It just looks like a faint pinpoint of greenish or bluish light.

Uranus's acceptance as a new planet overturned beliefs that had been held for millennia about the size of our Solar System, and kicked off a flurry of planetary discovery. But despite Uranus's significance, we haven't spent much time visiting the planet. A flyby by Voyager 2 in 1986 marks the only time we've explored it. Because of this, we simply don't know a great deal about Uranus. Until telescope observations in the past few decades, we thought of it as a rather bland planet: dark, cold, slow and with few interesting features.

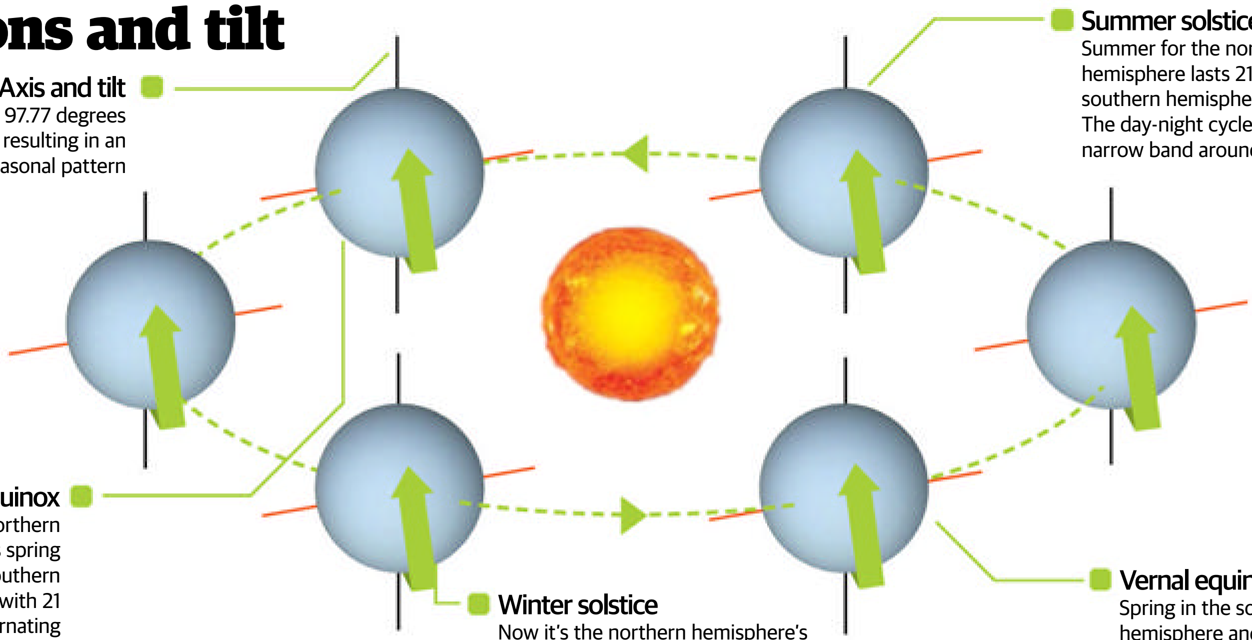
Uranus is the third-largest planet by radius and the fourth-largest by mass. It's about 3 billion kilometres (1.86 billion miles) from the Sun, which means that it receives 0.0025 per cent of the sunlight that the Earth gets. Uranus is a gas giant, along with Jupiter, Saturn and Neptune, with the latter planet sometimes being referred to as its twin. It is the least massive of the four, but still more than 14 times more massive than Earth. Uranus has a diameter four times that of Earth's. It also has the coldest atmosphere of any other planet in the Solar System, with a mean temperature of approximately -197 degrees Celsius (-322 degrees Fahrenheit). Uranus also has a multilayered cloud system, although without the flashy variations of colour seen on planets such as Jupiter and Saturn. However, it does have a lot in common with the other gas giants. It has a magnetosphere that is very similar to Jupiter's. It has 27 moons, and a system of 13 rings that was discovered not long after Saturn's ring system. It's most like Neptune in terms of composition, mostly hydrogen and helium with icy volatiles. Sometimes Uranus and Neptune are referred to as the 'ice giants'.

But Uranus can't just be lumped in with the other gas giants because the planet has its own unique twist. Literally, as Uranus's 97.77-degree axial tilt means that it is parallel with the plane of the Solar System - its poles are on either side. While other planets have extreme tilts, none are so perfectly perpendicular to the plane of its orbit. Recent studies show that Uranus is probably tilted due to at least two violent, massive collisions one after another, with objects larger than Earth. These impacts likely occurred early in the planet's life, even before its moons formed, and have made astronomers rethink how the other gas giants formed as well.

The tilt has impacted just about everything about Uranus. It has extreme seasons and weather fluctuations since each hemisphere experiences either full Sun or deep space. Its magnetosphere is tilted and asymmetric. The ring system is also on its 'side', and comes close to rivalling Saturn's in complexity. The moon system is less massive than any other gas giant's system. So, in many ways, Uranus is unique.

> "Uranus can't just be lumped in with the other gas giants as it has its own unique twist"

Seasons and tilt



Axis and tilt
Uranus is tilted 97.77 degrees on its axis, resulting in an unusual seasonal pattern

Summer solstice
Summer for the northern hemisphere lasts 21 years, while the southern hemisphere stays dark. The day-night cycle occurs only in a narrow band around the equator

Autumnal equinox
Autumn in the northern hemisphere is spring in the southern hemisphere, with 21 years of alternating days and nights as the equator faces the Sun

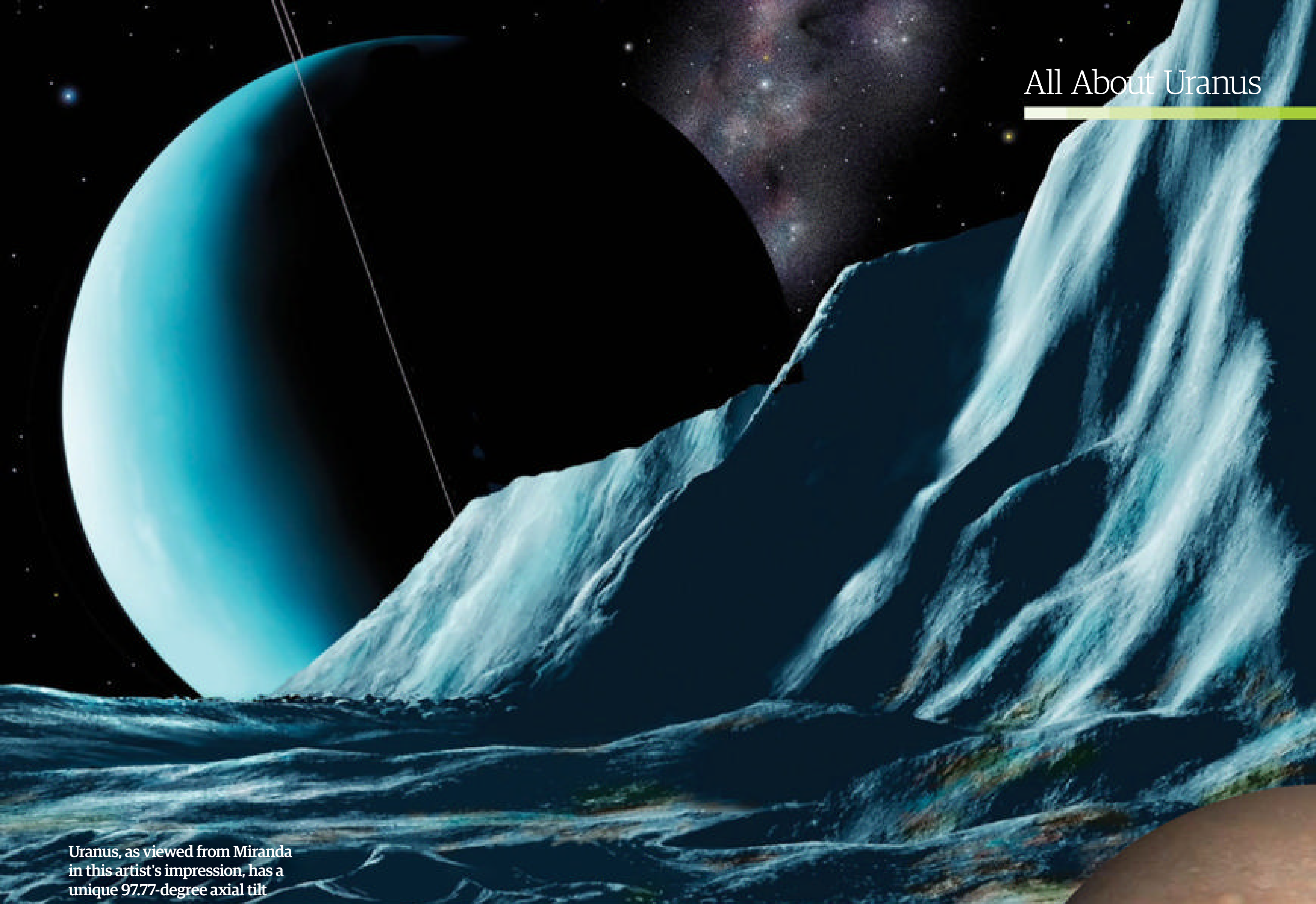
Winter solstice
Now it's the northern hemisphere's turn to stay dark for 21 years, while the southern hemisphere has sunlight

Vernal equinox
Spring in the southern hemisphere and autumn in the north means another 21 years of alternating days and nights

The planets in relation to the Sun

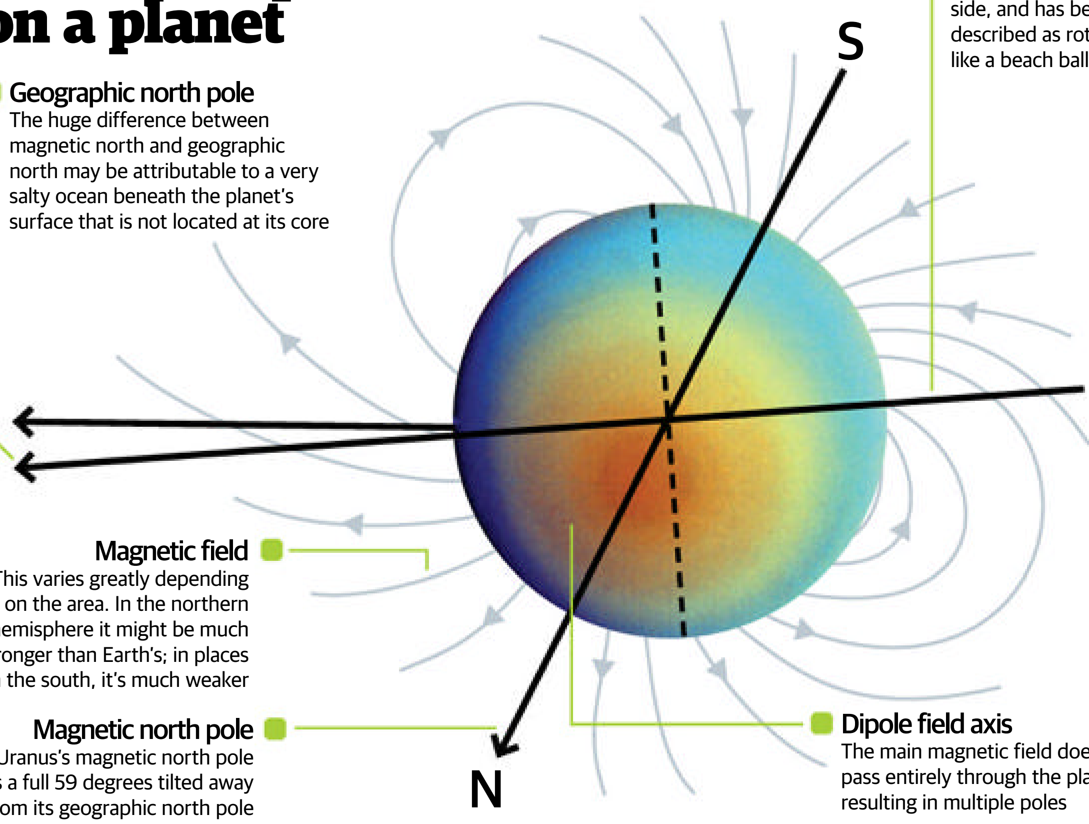
All figures = million miles from Sun

Uranus lies 3 billion km (1.86 billion mi) from the Sun on average, and 2.57 billion km (1.6 billion mi) from Earth



Uranus, as viewed from Miranda in this artist's impression, has a unique 97.77-degree axial tilt

A unique spin on a planet



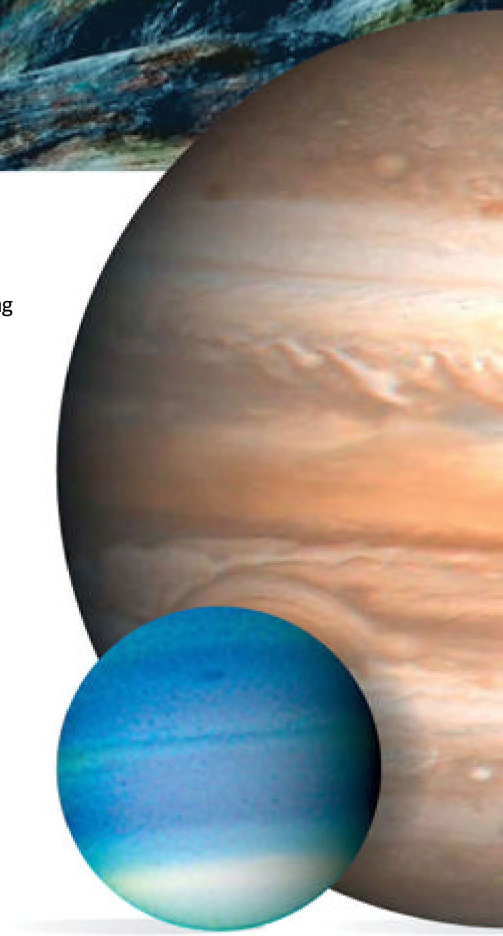
Geographic north pole
The huge difference between magnetic north and geographic north may be attributable to a very salty ocean beneath the planet's surface that is not located at its core

Spin axis
Uranus spins on its side, and has been described as rotating like a beach ball

Magnetic field
This varies greatly depending on the area. In the northern hemisphere it might be much stronger than Earth's; in places in the south, it's much weaker

Magnetic north pole
Uranus's magnetic north pole is a full 59 degrees tilted away from its geographic north pole

Dipole field axis
The main magnetic field does not pass entirely through the planet, resulting in multiple poles



Compared to Saturn and Jupiter, Uranus and Neptune are very small gas giants. But Uranus is still more than 60 times greater in volume, 14 times greater in mass and four times greater in diameter than Earth

Uranus inside and out

It has a very similar structure to Neptune but this ice giant still retains its mysteries

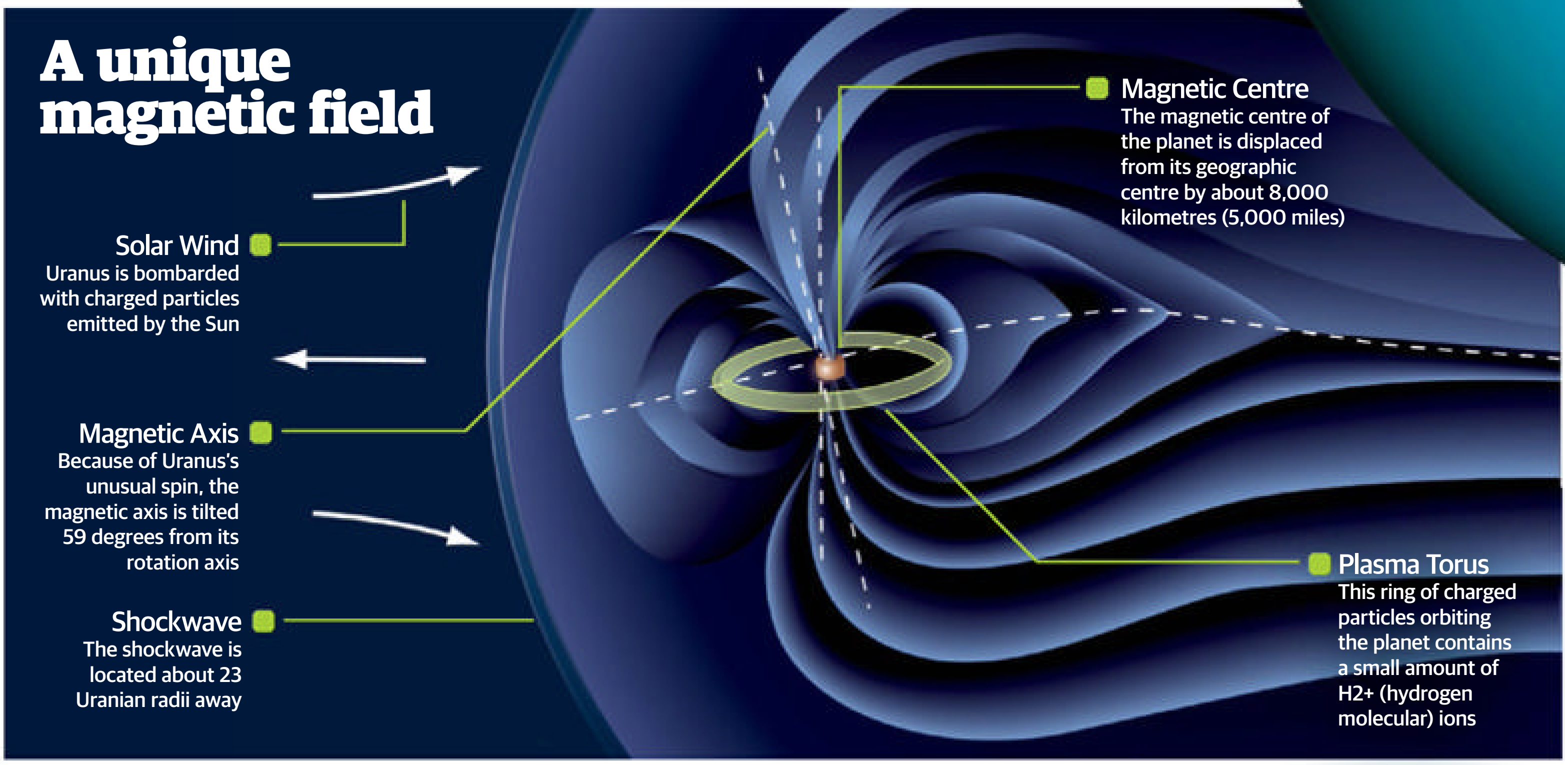
The term 'gas giant' implies that Uranus is solely composed of gases, but studies indicate that it actually has a core of silicate rock, encased in ices and topped with a gaseous layer. The core must be very small, since Uranus is the second-least dense planet. It likely takes up only 20 per cent of the planet's radius. The ice mantle surrounding the core is fluid, with volatiles like methane, ammonia and water. In fact, this electrically conducive fluid is often called an ammonia-water ocean. The outer layer is mostly helium and hydrogen.

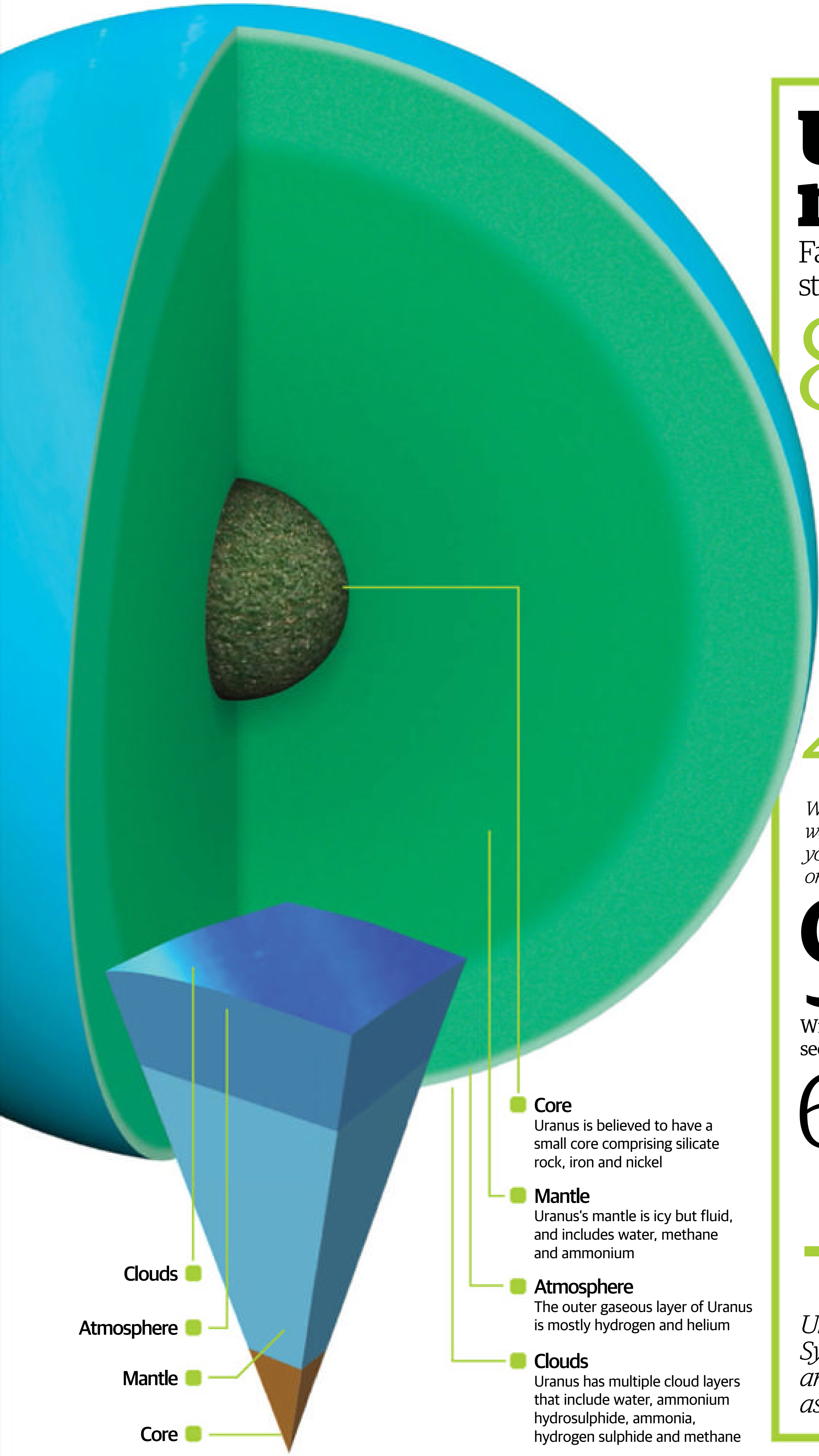
Uranus is also much cooler inside than the other gas giants – it's actually the coldest planet in the Solar System. Neptune radiates 2.61 times the heat that Uranus does. We aren't sure why Uranus is so cold in comparison, but it may have been struck by a large body that forced it to expel most of the heat it had when formed, or there could be a complex system at work in the atmosphere that keeps core heat from getting out.

The atmosphere contains three layers: the thermosphere, the stratosphere and the troposphere. The lowest layer, the troposphere, is the most interesting and is rich in volatile ices like methane and ammonia. It has four cloud layers: methane, hydrogen sulphide and ammonia, ammonium hydrosulphide, and water clouds at the upper limit. We've only observed the top two layers, along with a hazy layer above them. The stratosphere sits between the troposphere and the outermost layer, the thermosphere. Uranus tends to look light bluish or greenish in colour, and it has faint darker bands. The overall colour is due to the way that methane absorbs visible and near-infrared light.

Until Voyager 2 explored Uranus's atmosphere, we didn't know much about its features. The probe found a bright polar cap at the south pole, as well as a lighter band called a collar. There were darker bands in the southern hemisphere and about ten lighter clouds around the middle latitudes. The timing of Voyager 2's arrival meant that it could not fully observe the northern hemisphere. In the Nineties, Hubble and ground-based telescopes like the Keck Observatory began to see more atmospheric features on Uranus. They spotted many more clouds in the northern hemisphere, which are brighter and at a higher elevation than the ones in the southern hemisphere. They also observed in 2007 that the southern collar had nearly disappeared, while one in the north had grown.

A unique magnetic field





Uranus in numbers

Fantastic figures and surprising statistics about the distant planet

$8.69m/s^2$

The acceleration due to gravity on Uranus, compared to $9.8m/s^2$ on Earth

84 years

It takes Uranus 84 years to complete its orbit around the Sun

9 years

The number of years it took Voyager 2 to reach Uranus after launching from Earth. Voyager 2 is still going strong after 35 years

40kg

What you would weigh on Uranus if you weigh 45kg (100lb) on Earth

900km/h

Wind speeds on Uranus can reach 250 metres per second (900km/h, 560mph)

60x

Uranus's volume is more than 60 times that of Earth

-197°C

Uranus is the coldest planet in the Solar System, with an average temperature of around -197°C (-322°F). It can get as low as -224°C (-497°C)

Moons and rings

Uranus has 13 rings and 27 moons, but we could continue to find more

Discovering the Uranian ring system was a real surprise for astronomers. Since the planet is on its side, we have the opportunity to view the rings in a completely different way than we have for the rings of Jupiter and Saturn. Most of the rings were identified in 1977, with Voyager 2 and later the Hubble Telescope bringing the total to its current number of 13. Many of these rings are not quite in the plane of Uranus's equator, and most of them are not exactly circular. Unlike the rings of Jupiter, most of Uranus's rings comprise mostly microscopic particles of water ice and an unknown material - not dust. And in comparison to Saturn's rings, Uranus's rings are very dark. The brightness seems to vary depending on the angle of the ring.

Usually the Uranian rings are classified into three different groups. The nine main ones are very narrow - 6, 5, 4, Alpha, Beta, Eta, Gamma, Delta and Epsilon. The two dustier rings are in their own group: Zeta (1986U2R) and Lambda. The two outer rings are Nu and Mu. The brightest and densest ring of the whole system is Epsilon. It is also the most eccentric, with a thickness that varies from 19.7 kilometres (12 miles) to 96.4 kilometres (59 miles). All of the rings seem to be very young in comparison to the planet. This means that they must be replenished by things like collisions of larger particles, moons or meteorites. The Epsilon ring has shepherd satellites - two moons, Cordelia and Ophelia - that confine it and define its inner and outer edges. But how do the rings without shepherd satellites maintain their shape and not spread out? This could mean that there are more moons we haven't seen.

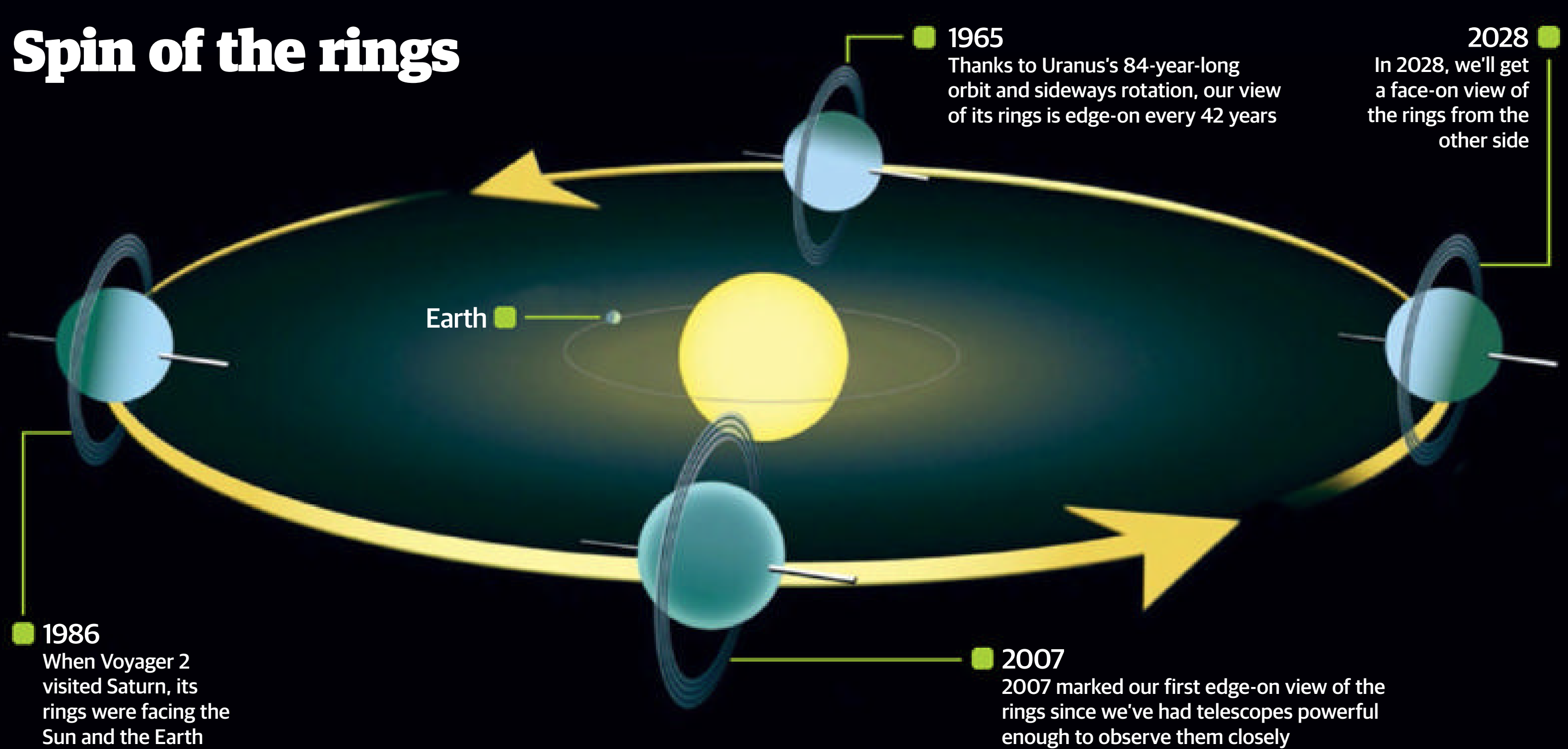
All 27 of Uranus's moons are named after characters from the writings of either Alexander Pope or William Shakespeare. The first ones to be discovered were Titania and Oberon, seen by William Herschel in 1787. The most recent discoveries, such as Cupid and Francisco, were made using the Hubble Space Telescope in 2003. Despite their number, the moons aren't very massive - the mass of the five major moons combined is less than half of the mass of Triton, Neptune's largest moon. These major moons are Miranda, Ariel, Umbriel, Titania and Oberon. The largest of these is Titania, with a radius of 789 kilometres (490 miles). All of the major moons have planetary mass and hydrostatic equilibrium - meaning that they have enough gravity to keep them spherical. If they were in orbit around the Sun instead of Uranus, they would probably be considered dwarf planets. Except for Miranda, which is primarily ice, the major moons seem to be equally rock and ice. The largest ones might even have differentiated interiors, with cores and mantles. They're mostly heavily cratered from impacts with meteors and other objects. And, except for Umbriel, they all show signs of geological activity.

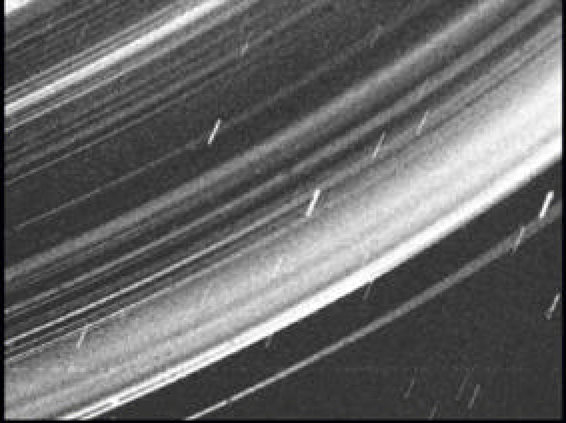
Inside Miranda's orbit lie 13 inner moons, each of which are associated with one of the rings. We know very little about most of these moons - only Puck was imaged by Voyager 2. It's the largest at 162 kilometres (100 miles) in diameter. These small moons are generally dark coloured and are highly perturbed by each other, with unstable orbits.

The nine irregular moons orbit very far away from Uranus compared to the other moons, and were probably captured by Uranus's gravitational pull soon after the planet formed. They have eccentric orbits and all but one, Margaret, are retrograde (meaning they orbit in the opposite direction of the planet). The largest at about 150 kilometres (93 miles) in diameter is Sycorax. There are likely to be even more irregular moons that we haven't yet discovered.

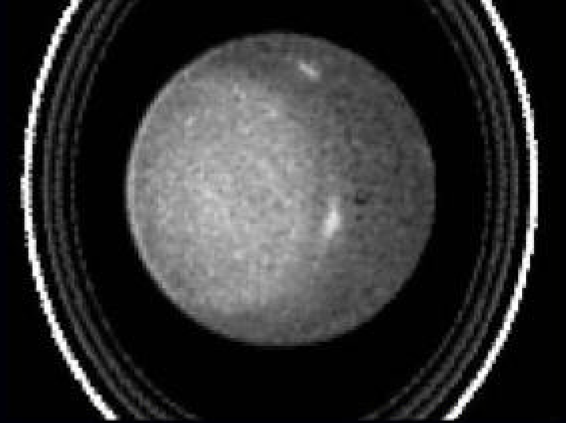
"The mass of the five major moons combined is less than half of Triton's mass"

Spin of the rings





This image, taken by Voyager 2, shows the small dust particles distributed throughout Uranus's ring system



This 1994 image taken by Hubble provided the first view of the south pole haze and the ring system since Voyager 2

The orbits of the moons

1. Miranda
The smallest and innermost of Uranus's five major moons, Miranda orbits the planet at around 129,390 kilometres (80,400 miles).

2. Mab
Although photographed by Voyager 2, Mab's existence was not confirmed until 2003. Its size is unconfirmed, but we know that it is highly perturbed by the orbits of neighbouring moons.

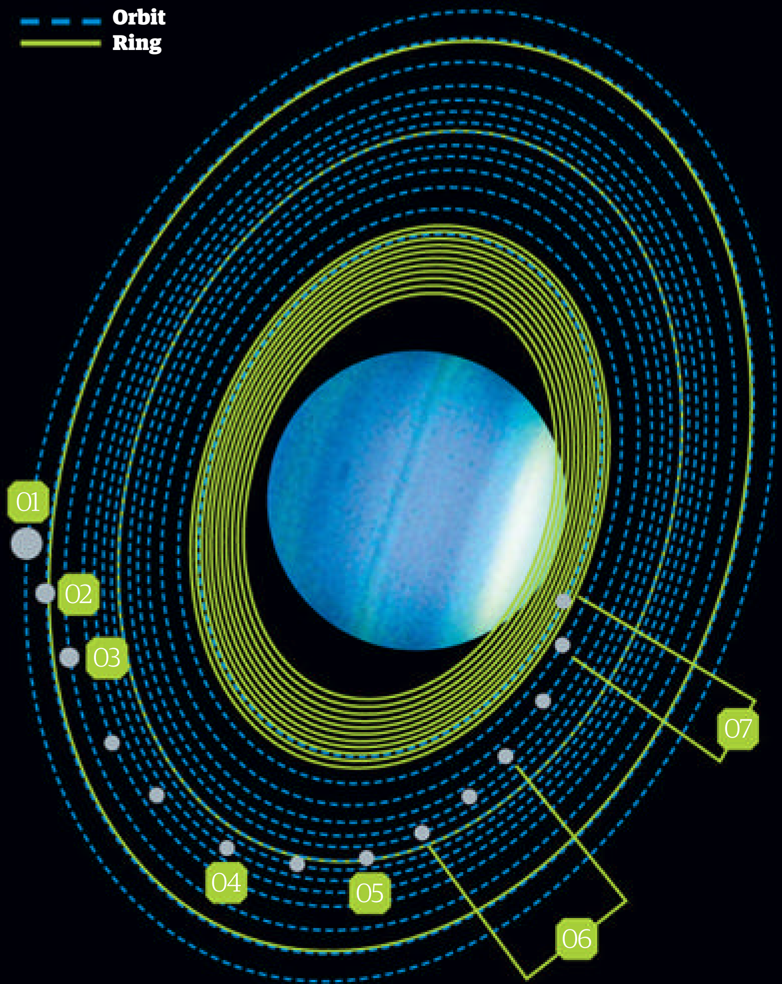
3. Puck
Puck is the largest inner moon of Uranus, and lies between the rings and Miranda, the first of the larger moons.

4. Cupid
Discovered in 2003, Cupid is the smallest of the inner moons at just 18 kilometres (11.2 miles) in diameter.

5. Portia
The second-largest inner moon, Portia heads a group of moons with similar orbits. It has a diameter of about 140 kilometres (87 miles).

6. Juliet, Desdemona and Cressida
Little is known about these small neighbouring moons, but their chaotic orbits may result in collisions within 100 million years.

7. Ophelia and Cordelia
These innermost known moons serve as shepherd satellites – defining the inner and outer edges of Uranus's Epsilon ring.



The major moons

Miranda
The innermost and smallest of Uranus's five major moons has a diameter of just 472km (290 mi)

Ariel
The fourth-largest moon, Ariel also has the third-greatest mass. Voyager 2 imaged about 35 per cent of its surface

Umbriel
Umbriel has the darkest surface of the Uranian moons, and is one of the most heavily cratered

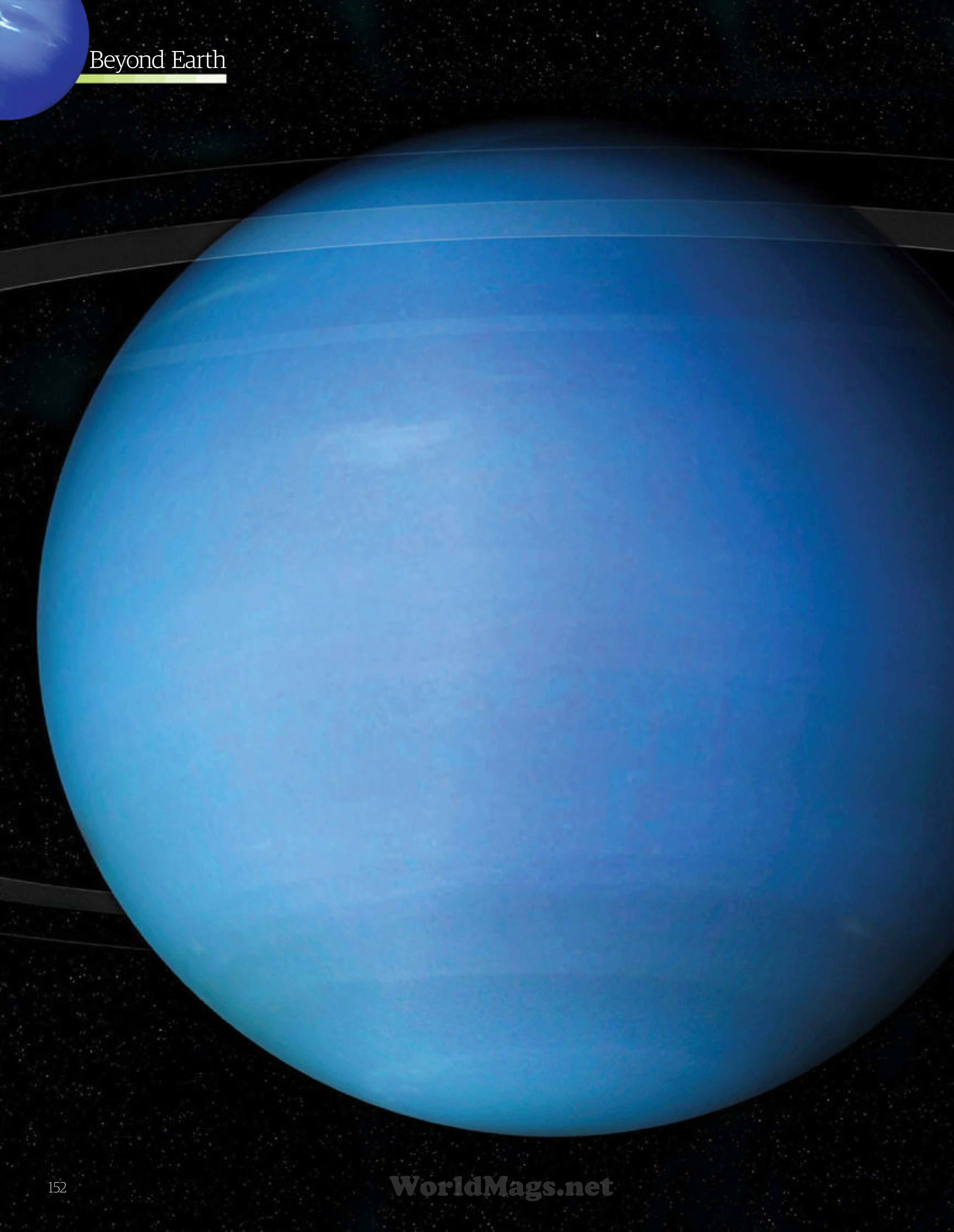
Titania
Titania is the eighth-largest moon in the Solar System with a diameter of around 1,580km (980 mi)

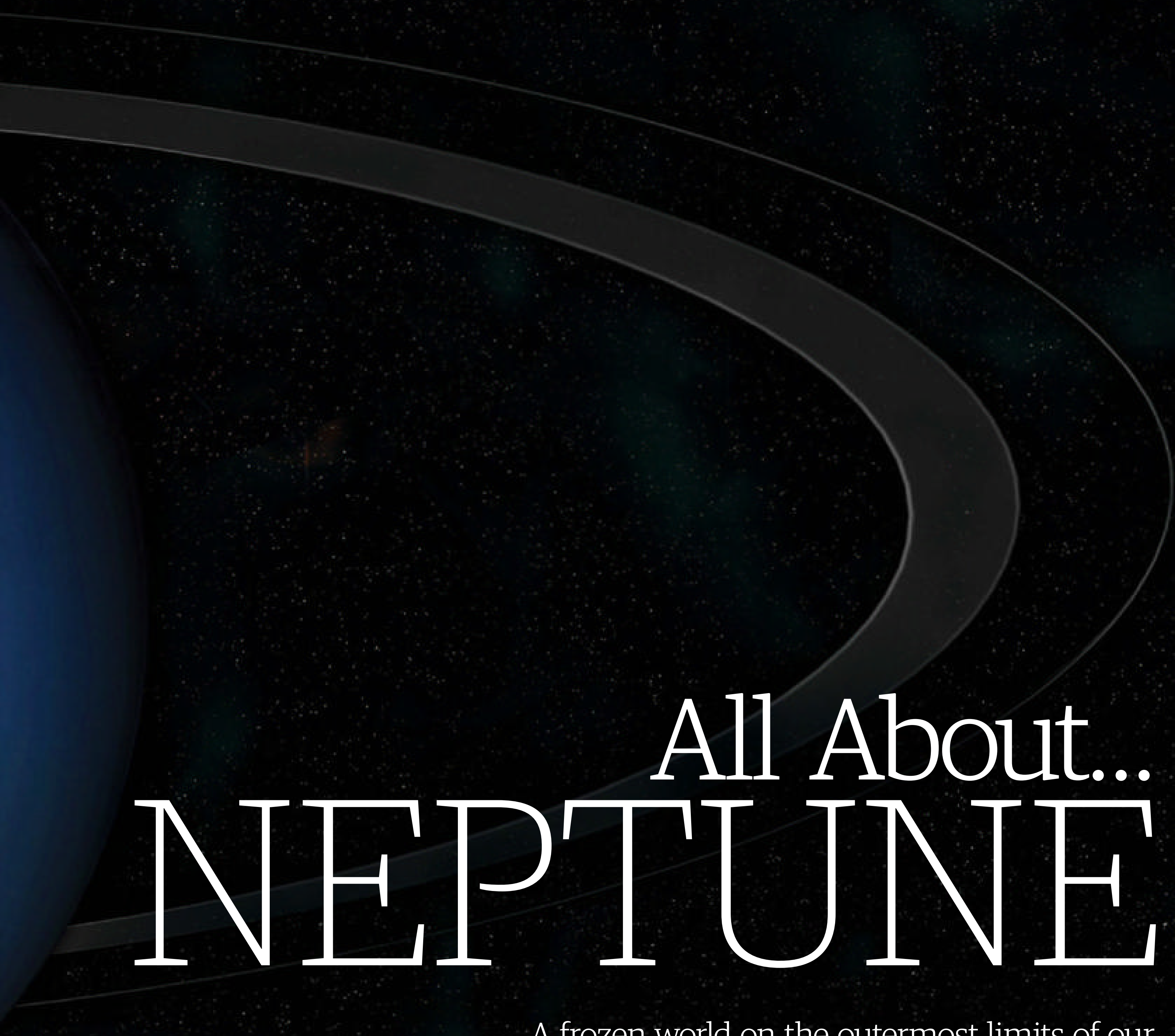
Oberon
Oberon is the outermost of the five major moons and is partially outside of Uranus's magnetosphere

Discovering the rings

When William Herschel discovered Uranus, he also claimed to see a faint ring around the planet. It seems unlikely he was truly able to see anything, however. The ring system was officially discovered by a team working with the Kuiper Airborne Observatory (KAO). In 1977 and 1978, the team found a total of nine rings around Uranus. KAO was the first airborne astronomical research observatory, based at the NASA Ames Research Center in California. A military jet aircraft was modified to carry a 91.5cm (36in) reflecting telescope used to conduct infrared astronomy. Why a telescope on a plane? The aircraft was used to fly above 13,716m (45,000ft). This altitude is above the layer of water vapour in the Earth's atmosphere that absorbs infrared radiation, allowing the team to use the telescope to observe other planets in our Solar System.

Dr James Elliot, an astrophysicist with the KAO team, was an expert in stellar occultation – learning about a planet by measuring the light blocked when it passed between the Earth and a distant star. While working with data recording during an observation of Uranus, Dr Elliot noticed that the light between the planet and the distant star went dim for a few minutes before Uranus appeared. This was the first evidence of the rings, confirmed by Voyager 2 about a decade later.





All About... NEPTUNE

A frozen world on the outermost limits of our Solar System, Neptune is a mysterious planet with its own unique characteristics

This image of the planet Neptune, seen as a small blue disc in the centre, was taken from the Earth in 1998 using a camera fitted to a telescope

Each planet is unique, and Neptune's claim to fame is being the first planet to be discovered not by observation, but by prediction. French astronomer Alexis Bouvard spent a lot of time closely observing the orbit of Uranus, and detected a gravitational perturbation that he deduced could only be explained by the existence of another planet. From his observations, other astronomers calculated the location of Neptune. To be fair, Galileo actually spotted Neptune more than 200 years before, but since he thought it was a star, he didn't get the credit.

There's still some debate over who did deserve the credit - French astronomer Urbain Le Verrier or British astronomer John Couch Adams - and some sources include a third astronomer, Johann Galle of Germany. At any rate, Galle was the first to look at Neptune and understand what he was seeing, using calculations from Le Verrier, on 23 September 1846. He discovered Neptune's largest moon, Triton, shortly afterwards. Given the distance - 4.3 billion kilometres (2.7 billion miles) from Earth - Neptune is not visible to the naked eye. But if you use strong binoculars or a telescope, you'll see the planet as a small blue disc. Until powerful modern telescopes on the ground and the invention of the Hubble Space Telescope, it was difficult to really study Neptune.

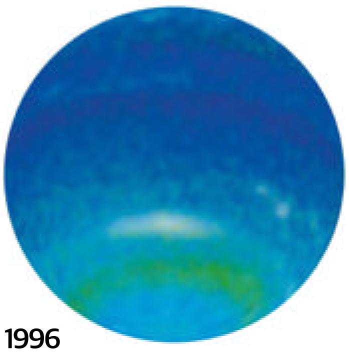
"Neptune has some of the fastest winds in the Solar System, at around 2,000km/h"

Neptune is the third-largest planet by mass, and 17 times the mass of Earth. It's also the fourth-largest planet by diameter. As the eighth planet from the Sun, Neptune was the furthest known planet until Pluto was discovered in 1930. Although it's back to being the outermost planet since Pluto's demotion, Neptune was still occasionally the outermost planet prior to that because Pluto's eccentric orbit caused it to cross inside Neptune's orbit on occasion. It's one of the four gas giants, and is also called Uranus's 'twin'. Because they're very similar in composition, both planets are often known as ice giants to distinguish them from Jupiter and Saturn. They're mostly made up of hydrogen and helium, with ices of water, methane, and ammonia, surrounding an icy rock core. While the methane content results in Uranus having a blue-green colour, Neptune is a brighter blue. We're not sure what in the atmosphere intensifies the colour. Neptune also has an extremely cold atmosphere like Uranus, topping out at about -218 degrees Celsius (-360 degrees Fahrenheit) in the upper levels.

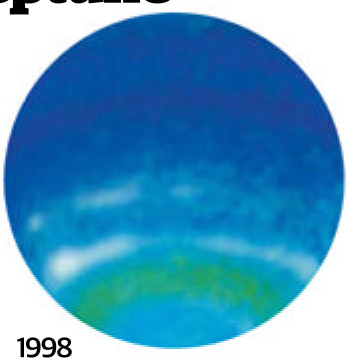
Although Neptune doesn't have the extreme horizontal tilt of Uranus, its magnetosphere is strongly tilted away from its rotational axis, at 47 degrees. Neptune also has a ring system and more than a dozen known moons. But that's where the similarities mostly end between the two planets. Uranus has a relatively dull atmosphere, for example, but there's lots happening weather-wise on Neptune. When Voyager 2 flew by in 1989 (the only spacecraft to visit Neptune), it observed lots of interesting weather. This includes some of the fastest winds in the Solar System, at around 2,000 kilometres per hour (1,240 miles per hour).

Neptune's tilt is much like Earth's at 28.32 degrees, so it has regular seasons, which happen to last about 40 years, because at 4.50 billion kilometres (2.8 billion miles) from the Sun, it has an orbit of 164.79 years. That means that in 2011, it completed its first orbit since it was discovered. Neptune's gravitational pull also has an impact on the Kuiper belt, a large ring of tiny, icy objects - including the dwarf planet, Pluto. Neptune's gravity has destabilised areas of the belt, and it has also created a resonance between the planet and at least 200 of the objects.

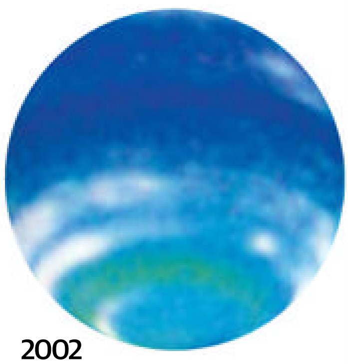
Seasons on Neptune



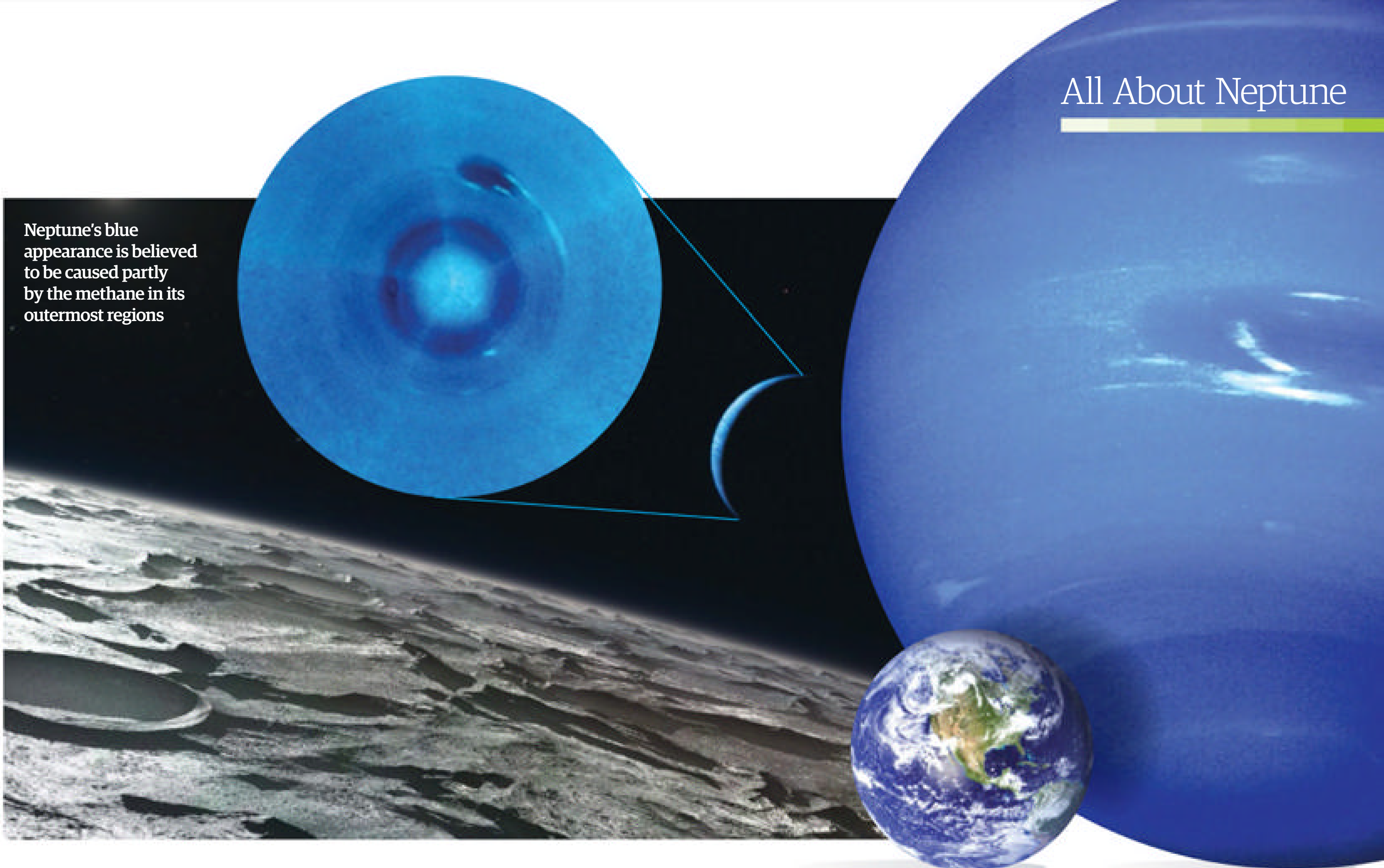
1996
Neptune has four seasons in each hemisphere, just like Earth, but each one lasts about 40 years.



1998
The cloud bands in the southern hemisphere brighten as spring begins on Neptune.



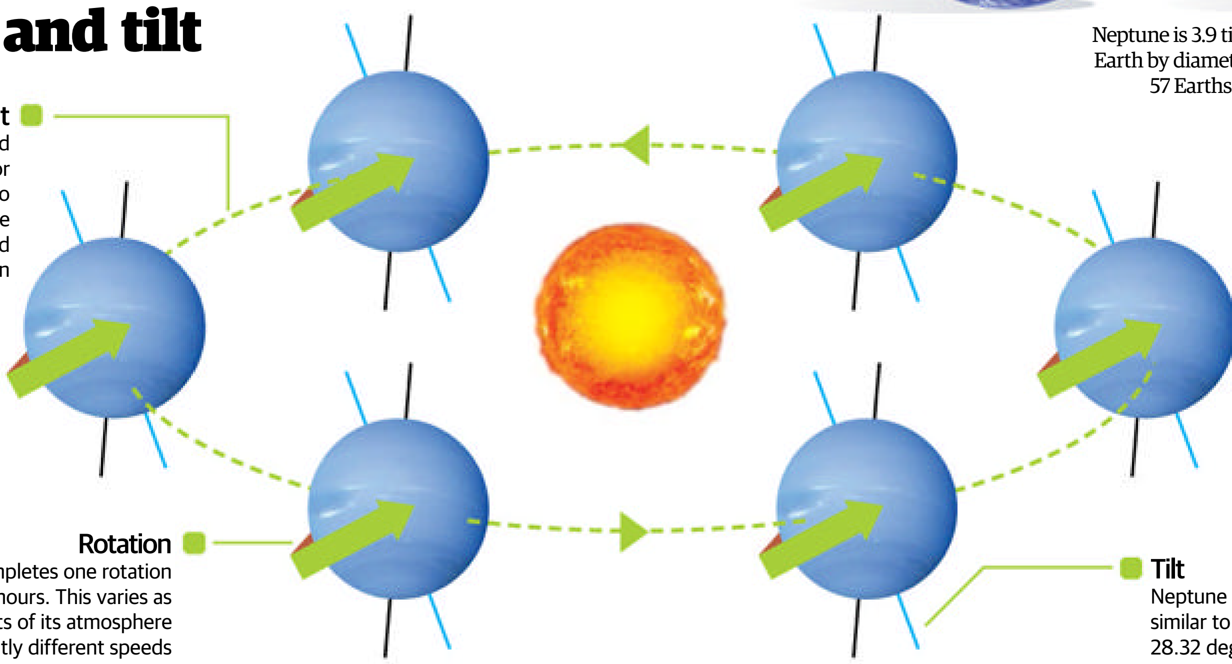
2002
There are about 20 more years of lightening clouds before the seasons change.



Neptune's blue appearance is believed to be caused partly by the methane in its outermost regions

Neptune is 3.9 times bigger than the Earth by diameter, and you could fit 57 Earths inside one Neptune

Orbit and tilt



Orbit
It takes around 164 years for Neptune to complete one orbit around the Sun

Rotation
The planet completes one rotation in about 16 hours. This varies as different aspects of its atmosphere rotate at slightly different speeds

Tilt
Neptune has an axial tilt very similar to that of Earth's at 28.32 degrees

The planets in relation to the Sun

Neptune lies 4.50 billion km (2.8 billion mi) from the Sun and 4.3 billion km (2.7 billion mi) from Earth

All figures = million miles from Sun

Neptune
The eighth planet from the Sun

Neptune inside and out

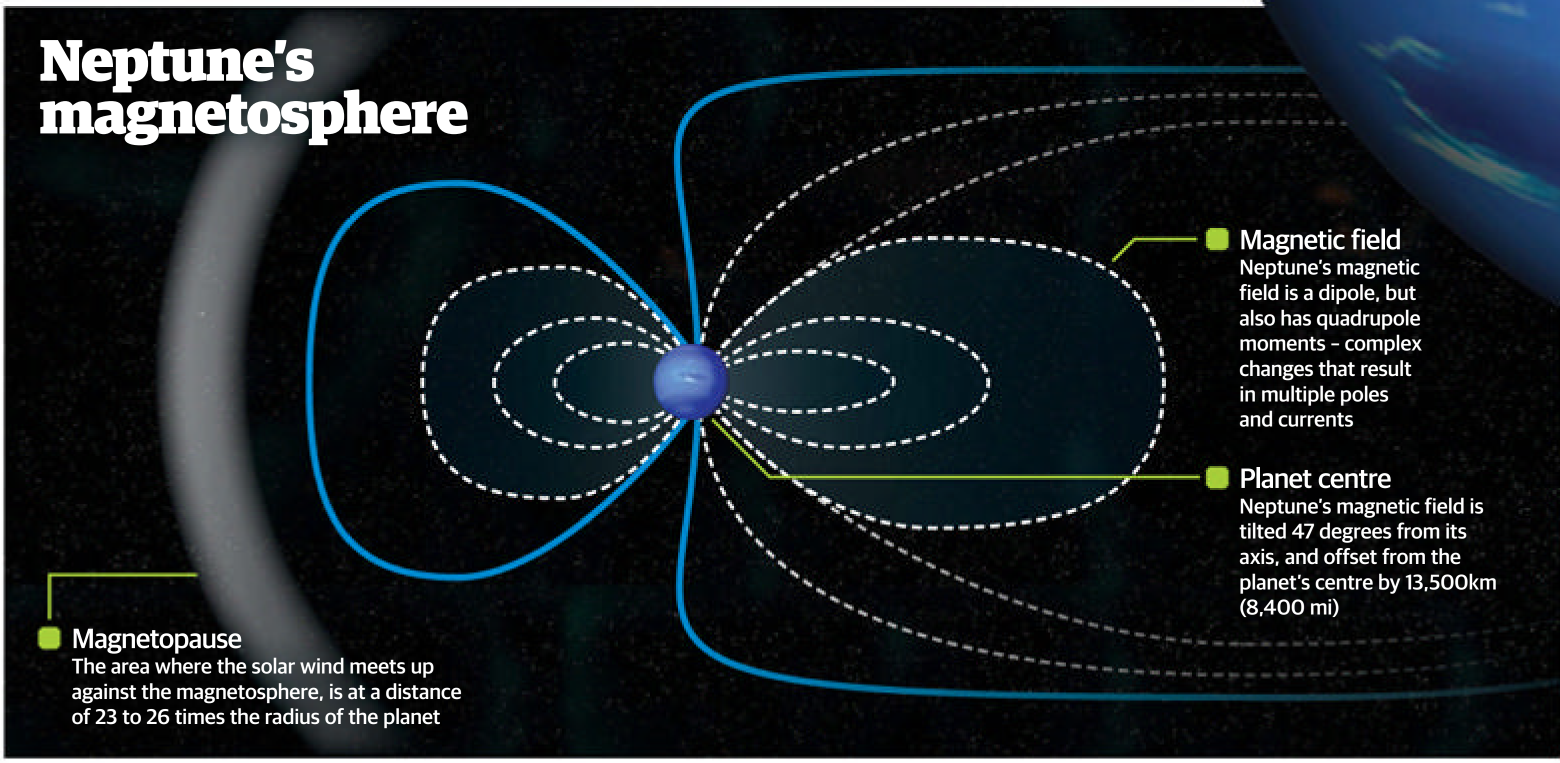
Neptune is a lot like Uranus, but brighter blue, warmer and with more active weather

Like Uranus, Neptune is a gas giant but not solely comprising gases. Its core contains silicate rock, iron and nickel and is a little larger than planet Earth. Neptune's core is also under great pressure (twice as much pressure as the Earth's core) and about 5,100 degrees Celsius (9,200 degrees Fahrenheit). The mantle surrounding the core is icy, but that's a relative term when it comes to planet temperatures because it's actually a hot, dense liquid. Made of methane, ammonia, and water, the mantle is electrically conductive and its temperature ranges between 1,700 degrees Celsius (3,100 degrees Fahrenheit) and 4,700 degrees Celsius (8,500 degrees Fahrenheit). The mantle may also consist of additional layers, including a layer of ionised water (with electrically charged hydrogen and oxygen) and a deeper layer of superionised water.

Neptune's atmosphere surrounding the mantle is about 80 per cent hydrogen, 19 per cent helium, and the rest traces of ammonia, water and methane. The methane, which absorbs red light in the spectrum, gives Neptune its colour. Since the atmospheric composition is supposed to be very similar to that of Uranus's, there must be something else in the atmosphere that makes Neptune a bright blue versus Uranus's bluish-green. It has two main divisions - the troposphere and the stratosphere. The troposphere probably has several different types of cloud bands, depending on where they're located. The lowest levels are clouds of hydrogen sulphide and ammonia. Then there are water ice clouds as the temperature drops, at a pressure of 50 bars. A cloud layer of water, hydrogen sulphide, ammonia and ammonium sulphide floats above five bars of pressure. Between one and five bars, in the uppermost layer of the troposphere, the clouds are ammonia and hydrogen sulphide. Bands of these clouds wrap around the planet, casting shadows on opaque clouds below them.

Neptune is warmer overall than Uranus. Its stratosphere has traces of carbon monoxide, and the thermosphere is unusually warm at 480 degrees Celsius (900 degrees Fahrenheit) given Neptune's distance from the Sun. The planet radiates more than twice the energy of Uranus and receives only 40 per cent of the sunlight of its twin, yet has about the same surface temperature. We aren't sure why, but these differences in heat may be why Neptune has weather like storms and high winds, while Uranus does not.

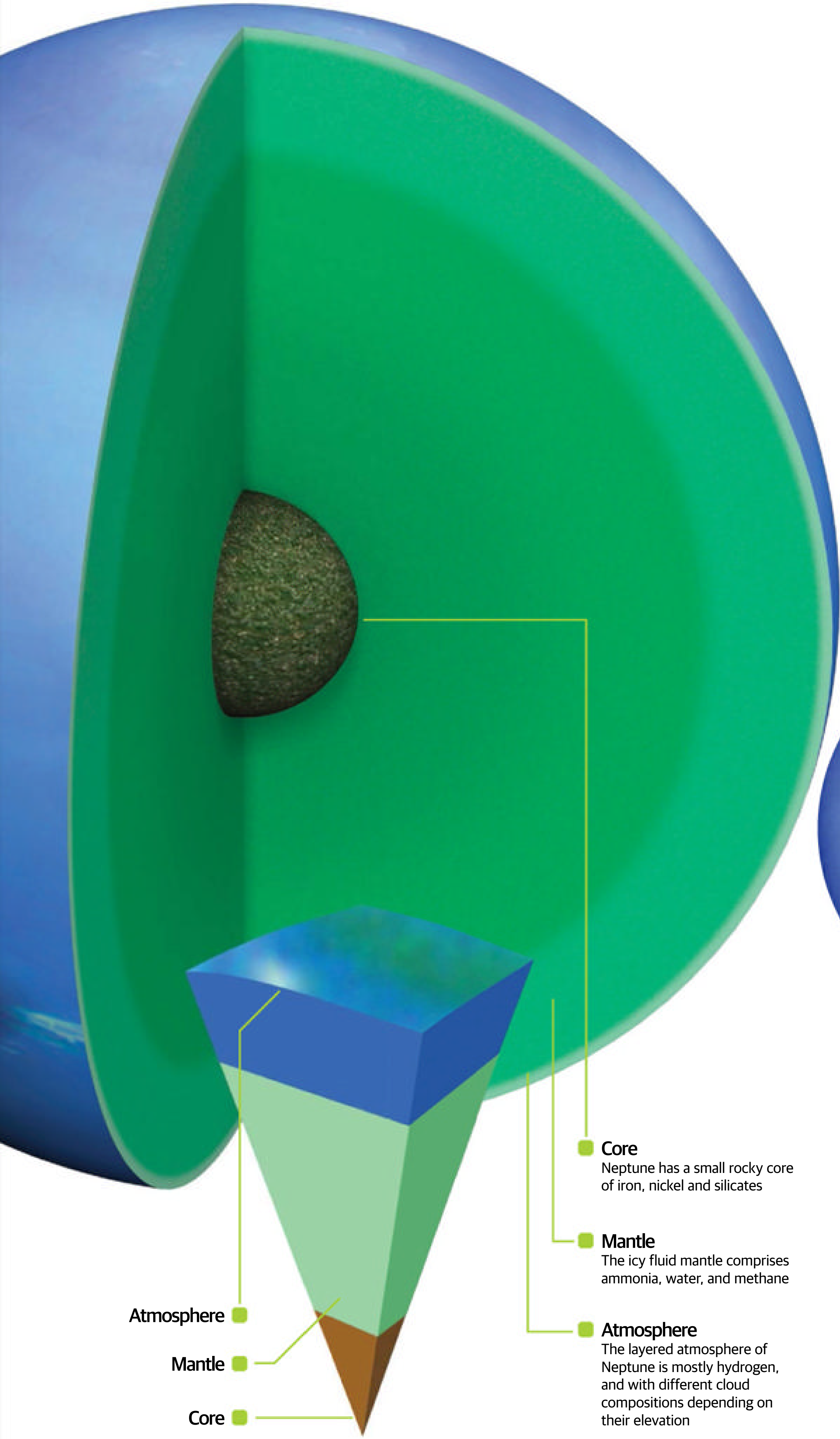
Neptune's magnetosphere



Magnetic field
Neptune's magnetic field is a dipole, but also has quadrupole moments - complex changes that result in multiple poles and currents

Planet centre
Neptune's magnetic field is tilted 47 degrees from its axis, and offset from the planet's centre by 13,500km (8,400 mi)

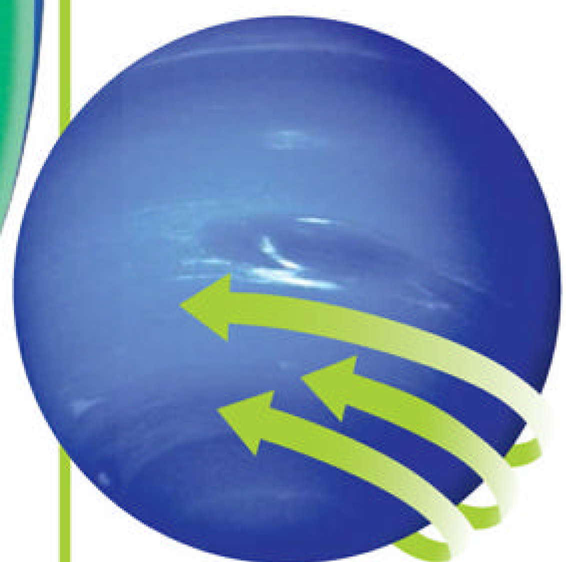
Magnetopause
The area where the solar wind meets up against the magnetosphere, is at a distance of 23 to 26 times the radius of the planet



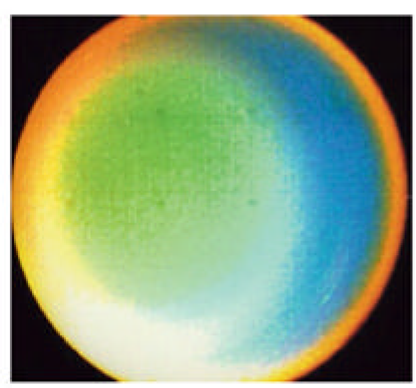
Supersonic winds and storms

Neptune's massive winds and storms set it apart from Uranus. Most of the winds blow in retrograde rotation (opposite the planet's rotation), but the general pattern is prograde rotation (in the direction of the planet) in the higher latitudes and retrograde rotation in the lower latitudes. The winds reach almost 2,000 kilometres per hour (1,240 miles per hour) – nearly supersonic speeds.

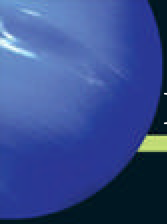
On Voyager 2's flyby in 1989, it observed a massive anti-cyclonic storm that was 13,000 by 6,600 kilometres (8,700 by 4,100 miles) in size. The storm was dubbed the Great Dark Spot. It wasn't present when the Hubble Space Telescope viewed the planet five years later, but another storm was found and given the name. Neptune also has other large storms named the Scooter and the Small Dark Spot.



Neptune has storms, including hurricane-force winds that constantly blow around the planet



Special processing of this Neptune image taken by Voyager 2 shows the variations in temperature in its atmosphere



Moons and rings

Neptune has two very different groups of moons – inner moons with regular, circular orbits, and outer moons with irregular, eccentric orbits

Neptune has 13 known moons. Triton is by far the largest moon, comprising more than 99 per cent of the total mass in orbit around the planet. It has a diameter of 2,705 kilometres (1,700 miles) and is the only spheroid moon. Triton was probably a dwarf planet in the Kuiper belt before being captured by Neptune's orbit. Astronomers believe it was captured instead of forming as a satellite because it has a retrograde orbit – it circles Neptune opposite of the planet's rotation. Triton has an irregular orbit, and is the second known moon (along with Saturn's moon Titan) to have an atmosphere. The atmosphere mostly comprises nitrogen, with some trace amounts of carbon monoxide and methane. It is also one of the coldest objects in the Solar System. The moon is very dense, and is probably two-thirds rock and one-third ice.

Triton is one of the seven outermost moons, which have irregular orbits. The next moon to be discovered, Nereid, was discovered in 1949. It is the third-largest moon. Unlike Triton, it has a prograde orbit. Nereid's orbit is also extremely eccentric – it gets as close as 1.4 million kilometres (850,000 miles) to Neptune, but is 9.6 million kilometres (5.9 million miles) at its furthest point. The cause of its eccentricity is unknown, but it may have been perturbed by Triton, or have been a Kuiper belt object like Triton that was captured. We don't know exactly what Nereid looks like or what shape it takes. Two of the other irregular moons, Sao and Laomedeia, have prograde orbits. Both were discovered in 2002. Halimede, Psamathe and Neso all have retrograde orbits. Halimede and Neso were discovered in 2002, and Psamathe a year later. Neso and Psamathe both orbit very far away from Neptune; Psamathe orbits at 48 million kilometres (30 million miles) away. Both of these moons may have come from a larger moon.

The six inner moons have regular, prograde orbits: Naiad, Thalassa, Despina, Galatea, Larissa and Proteus. Little is known about the four innermost moons, except that they are small and irregularly shaped. All of these likely formed from debris leftover when Triton was pulled into orbit. Naiad is the innermost moon and was discovered in 1989 by Voyager 2. It orbits just 23,500 kilometres (14,600 miles) above Neptune. Thalassa was discovered around the same time. These two innermost moons orbit between two rings, Galle and Le Verrier. Despina, the third-closest moon, lies inside the Le Verrier ring, and the next moon, Galatea, may serve as a shepherd moon, holding the Adams ring in place.

> "Triton comprises more than 99 per cent of the total mass in orbit around the planet"

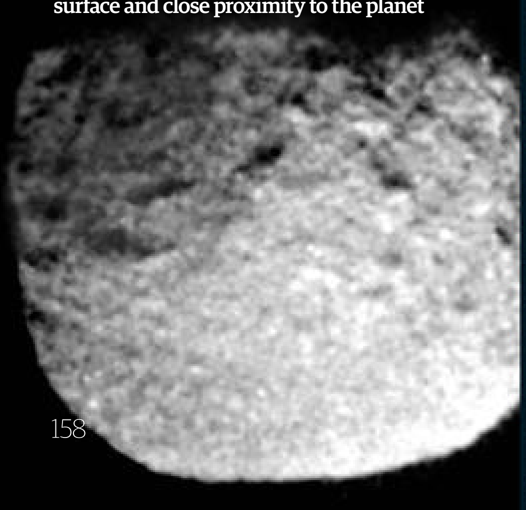
Larissa, the fourth-largest moon, was discovered in 1981. It is known to be about 200 kilometres (124 miles) in diameter and with an elongated shape. It's also heavily cratered. Proteus, the outermost of these moons, is also the second-largest moon in orbit around Neptune. Voyager 2 also discovered it, and we learned then that it is at least 400 metres (248.5 miles) in diameter. Proteus is also heavily cratered.

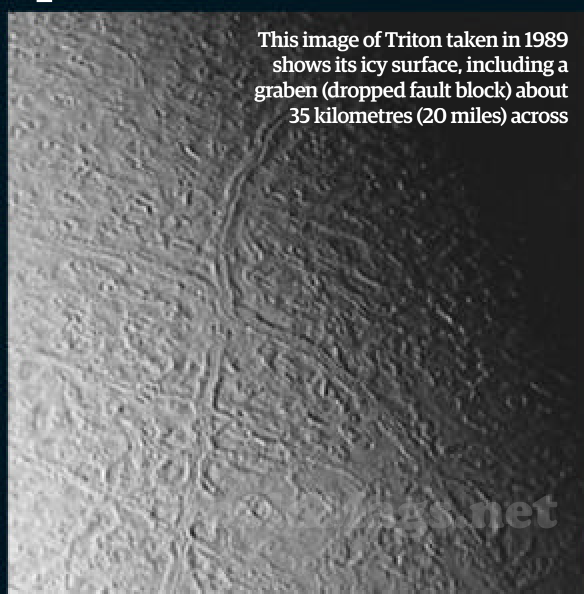
Neptune's ring system was first spotted in 1984 in Chile, by a group of international astronomers. Astronomers prior to this had suspected rings when observing dips in the brightness of stars viewed between the observer and the planet. The existence of the rings was proven by images taken by Voyager 2, and we have since viewed the brightest rings using the Hubble Space Telescope as well as Earth-based telescopes. There are five distinct rings, named in order of their distance from Neptune: Galle, Le Verrier, Lassell, Arago and Adams. Galle is a very faint ring, named after the first astronomer to view the planet. The next ring, Le Verrier, is extremely narrow at just 113 kilometres (70 miles) wide. Le Verrier may be confined by the moon Despina, which orbits just inside it.

Neptune's widest ring, Lassell, is also called the plateau. It's a thin sheet of dust stretching from Le Verrier to the next ring, Arago. Some don't consider Arago to be a ring at all; it looks like a bright rim around the edge of Lassell, but is less than 100 kilometres (62 miles) wide.

We know the most about the outermost ring, Adams. It is a narrow ring slightly slanted. The moon Galatea shepherds the Adams ring and creates 'wiggles', or perturbations, at 42 different places in the ring. Adams has an unusual feature: five bright spots called arcs located along the ring, where the particles of dust are clustered together. They're named Fraternité, Égalité 1, Égalité 2, Liberté and Courage. Courage is the faintest, while Fraternité is the brightest. Ground-based telescopes first detected them, and Voyager 2 confirmed their existence. They have dimmed slightly since their discovery and some of the arcs seem to have moved slightly, but overall they are stable. We just aren't sure why the dust particles have clustered together in those areas. There could be as-yet-undetected moons or moonlets, or the arcs could be caused by an unusual resonance with the moon Galatea.

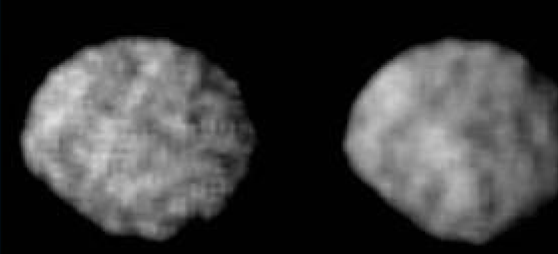
Although Proteus is the second-largest moon, it wasn't discovered until 1989 because of its dark surface and close proximity to the planet



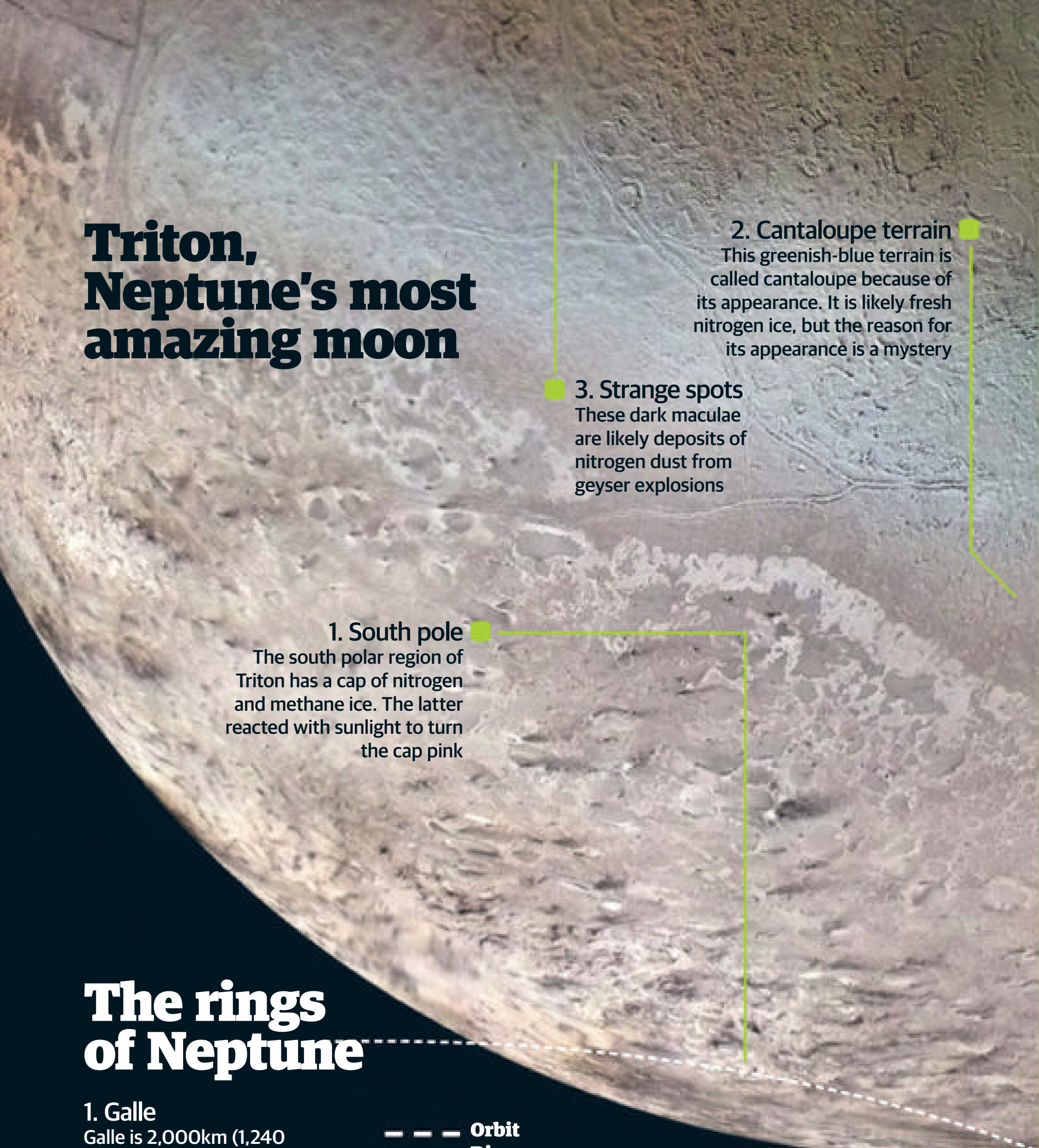


This image of Triton taken in 1989 shows its icy surface, including a graben (dropped fault block) about 35 kilometres (20 miles) across

Voyager 2 took these two images of Larissa, the fifth-closest moon of Neptune. It is cratered and irregularly shaped



Triton, Neptune's most amazing moon



The rings of Neptune

1. Galle
Galle is 2,000km (1,240 mi) wide and orbits Neptune at a distance of 41,000 to 43,000km (25,500 to 26,700 mi).

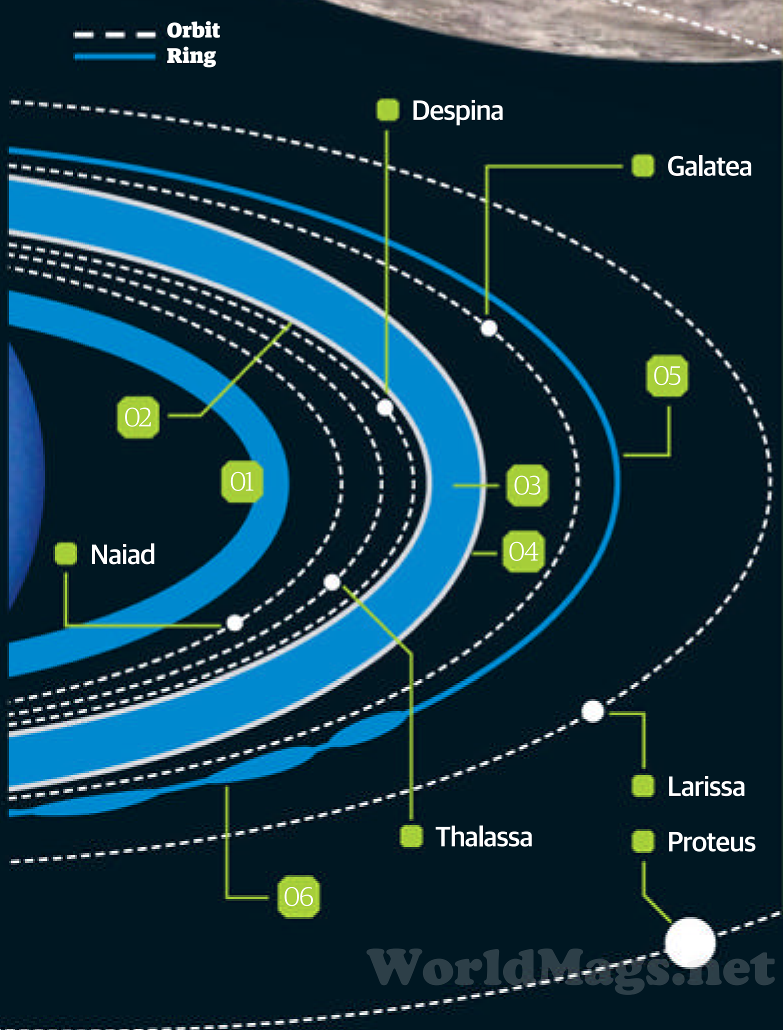
2. Le Verrier
Le Verrier is 113km (70 mi) wide and orbits 53,200km (33,000 mi) away.

3. Lassell
Lassell is more like a broad dust sheet than a ring, with its orbit around Neptune between 53,200 and 57,200km (33,000 and 35,500 mi).

4. Arago
Arago orbits Neptune at 57,200km (35,500 mi) and is less than 100km (62 mi) wide.

5. Adams
Adams is 35km (22 mi) wide and orbits around Neptune at 62,900km (39,000 mi).

6. Arcs
These arcs are the particles of dust clustered together in the Adams ring, named Fraternité, Égalité 1, Égalité 2, Liberté and Courage.



Neptune in numbers

Fascinating figures about the eighth planet from the Sun

500,000

A 1999 study at the University of California simulated the atmospheric pressure of Neptune and estimated it to be 100,000 to 500,000 times that of the Earth's

17%

Neptune's gravity is only 17% stronger than Earth's gravity – the closest of any planet in the Solar System

248 years

Neptune will be closer in its orbit to Pluto than to the Sun for 248 years, as Pluto's eccentric orbit takes it inside Neptune's

1/900

Neptune receives 1/900th of the energy from the Sun that the Earth receives

2

Triton is locked in synchronous rotation with Neptune, so one side always faces it. But because of its unusual orbit, both poles still get time in the Sun

100yrs

Neptune's moons are named after Greek and Roman water deities, since the planet is named after the god of the sea. None of the moons were named immediately after discovery – in Triton's case, it took over 100 years

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